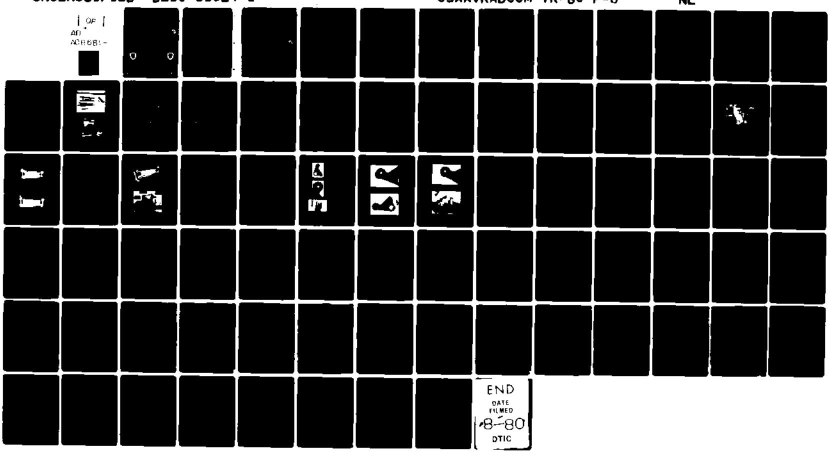
AD-A086 818 BOEING VERTOL CO PHILADELPHIA PA F/G 11/6
EVALUATION OF FORGED HELICOPTER COMPONENTS PROCESSED WITH CONTR--ETC(U)
JUN 80 W L WEISS DAAA25-77-C-0015
UNCLASSIFIED D210-11524-1 USAAVRADCOM-TR-80-F-6 NL



AD

ADA086818

REPORT NO. TR80-F-6

EVALUATION OF FORGED HELICOPTER COMPONENTS PROCESSED WITH CONTROLLED SOLIDIFICATION AND THERMAL-MECHANICAL TREATMENTS

LEVEL III

William L. Weiss
Boeing Vertol Company
P.O. Box 16858
Philadelphia, Pennsylvania 19142

Final Report Contract Number DAAA25-77-C-0015

U.S. ARMY AVIATION RESEARCH AND DEVELOPMENT COMMAND ST. LOUIS, MISSOURI	**U.S. ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND** DOVER, NEW JERSEY

JUNE 1980

(18) USAAVRADCOM

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(19) **REPORT DOCUMENTATION PAGE**

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: TR80-F-6	2. GOVT ACCESSION NO.: AD-A086 818
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): (6) EVALUATION OF FORGED HELICOPTER COMPONENTS PROCESSED WITH CONTROLLED SOLIDIFICATION AND THERMAL-MECHANICAL TREATMENTS	5. TYPE OF REPORT & PERIOD COVERED: (9) Final Report, Dec 1976 – June 1980
	6. PERFORMING ORG. REPORT NUMBER: (14) D210-11524-1
7. AUTHOR(s): (10) William L. Weiss	8. CONTRACT OR GRANT NUMBER(s): (15) DAAA25-77-C-0015
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Boeing Vertol Company, Box 16858, Philadelphia, PA 19142	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: AVRADCOM MANTECH Project 1758120 AMCMS Code: 1497.94.5.S8120(XH5)
11. CONTROLLING OFFICE NAME AND ADDRESS: U.S. Army Aviation Research and Development Command ATTN: DRDAV-EXT, P.O. Box 209, St. Louis, MO 63166	12. REPORT DATE: (11) June 1980
	13. NUMBER OF PAGES: 76
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): U.S. Army Armament Research and Development Command ATTN: DRDAR-SCM-P, Dover, New Jersey 07801 (12) 76	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

DTIC ELECTE JUL 17 1980 D

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aluminum	Fracture toughness	Structure
Forging	Fatigue-crack propagation	Microstructure
Thermal-mechanical treatment	Materials	Metallurgy
Fatigue	Mechanical properties	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A four task program was conducted to provide information for evaluating helicopter dynamic system components fabricated from aluminum alloy forgings produced with advanced processing techniques. Components produced with the advanced techniques, involving intermediate thermal-mechanical treatment of ingots, were tested side-by-side with conventionally produced components. Tests were conducted to determine fatigue strength and damage tolerance characteristics of the components.

DD FORM 1473, 1 JAN 73 — EDITION OF 1 NOV 65 IS OBSOLETE

403682

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

PREFACE

The Boeing Vertol Company of Philadelphia, Pennsylvania, prepared this report to satisfy the requirements of Contract DAA 25-77-C-0015, "Improvement of Helicopter Skin Material by Controlled Solidification and Thermal Mechanical Treatment."

This project was accomplished as part of the US Army Aviation Research and Development Command Manufacturing Technology program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army materiel. Comments are solicited on the potential utilization of the information contained herein as applied to present and/or future production programs. Such comments should be sent to: US Army Aviation Research and Development Command, ATTN: DRDAV-EXT, P.O. Box 209, St. Louis, MO 63166.

The U.S. Army Aviation Research and Development Command Project Engineer was Mr. G. Gorline and the U.S. Army Armament Research and Development Command Contract Technical Supervisor was Dr. J. Waldman.

The Boeing Vertol Company acknowledges the support of the Aluminum Company of America in conducting this program.

Boeing Vertol Company personnel responsible for this program were Mr. L. J. Marchinski, Program Manager; Mr. J. C. Zola, Project Engineer for initial phases of the program, and Mr. W. L. Weiss, Project Engineer for latter phases of the program. The component fatigue testing was accomplished by Mr. B. D. Austin and Mr. B. J. Johnston. Aluminum Company of America personnel key to this program included: Mr. G. Williams who supervised the intermediate thermal-mechanical treatment forging operations at ALCOA's Cleveland Works, and the late Mr. J. E. Vruggink, who supervised the final thermal treatments at ALCOA Laboratories and also was the Program Supervisor for ALCOA.

TABLE OF CONTENTS

Page

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

Under Contract DAAA 25-74-C-0448, the Boeing Vertol Company and the Aluminum Company of America conducted a program to evaluate the properties of thermally/mechanically processed and heat-treated 7475 aluminum alloy forgings in 25-, 51-, and 170-mm (1.0-, 2.0-, and 6.7-inch) thicknesses. A four task program was conducted to provide information for the development of industrial techniques for producing improved aluminum alloy forgings. These techniques, involving intermediate thermal-mechanical treatment of ingot, were evaluated on the basis of microstructure, mechanical properties, fracture and fatigue properties, and resistance to stress corrosion. The details of that program are presented in Reference 1.

The results of that program, which primarily involved testing of coupons of material, indicated weight and/or cost savings are possible by the use of thermal/mechanical treatment of 7475 aluminum alloy. With respect to the program goal; to achieve in Intermediate Thermal-Mechanical Treated (ITMT) aluminum alloy forgings, properties which are equivalent to or twenty percent better than conventional 7075-T73 forging properties, the following specific measures of mechanical properties performance were realized:

1. The tensile properties of ITMT aluminum alloy forgings are equivalent to those of 7075-T73 forgings.

2. The fracture-toughness values of ITMT aluminum alloy forgings are as much as 62 percent higher than those of conventional 7075-T73 forgings.

3. The fatigue properties of ITMT aluminum alloy forgings are 5 to 75 percent better than conventional 7075-T73 forging properties.

4. The stress corrosion properties of ITMT aluminum alloy forgings are equivalent to those obtained by conventional 7075-T73 forging practices.

On the basis of the potential identified for a cost effective means of saving weight in helicopter components, it was recommended to implement a program for the fabrication and evaluation of actual helicopter components using ITMT process aluminum alloy forgings.

The program described herein could be considered Phase II of the program referred to previously. In the present program the special technologies of the material producer and airframe manufacturer have again been combined. The material producer, the Aluminum Company of America, applied recently developed methods of forging fabrication to produce helicopter component forgings. The airframe manufacturer, the Boeing Vertol Company, coordinated the fabrication of the components and conducted the structural evaluation. This evaluation considered two types of helicopter components, a bellcrank and a drive scissors arm. Samples of each type of component were fabricated from three aluminum alloy forging systems; two ITMT processed aluminum alloys and one conventionally processed aluminum alloy.

DISCUSSION

The Boeing Vertol Company, with subcontracted support from the Aluminum Company of America, conducted a four task program to provide and test helicopter dynamic system components manufactured from intermediate thermal-mechanical treated aluminum alloy forgings. This program is considered Phase II to the program conducted under Contract DAAA 25-74-C-0448. Therefore, in the list of tasks which follow, the task numbers start with number V; the previous four tasks having been accomplished under the previously cited contract.

The primary objectives of this program (Phase II) are to demonstrate that ITMT processes can be applied to production forgings ranging in thickness from 13 to 76mm (0.5 to 3.0 inches), and that improvements similar to those measured in coupons can be achieved in actual helicopter hardware.

To achieve these objectives, four tasks were identified for accomplishment.

TASK V PROVIDE PRODUCTION FORGINGS

Task V primarily involved fabrication of production forgings. These forgings were provided for the following helicopter dynamic system components meeting the objective dimensional requirements.

Helicopter Model	Component	Forging Nominal Thickness Dimension (mm)
CH-46	Drive Scissors Arm	13 to 51 (0.5 to 2.0 inches)
CH-46	Lateral Differential Bellcrank	51 to 76 (2.0 to 3.0 inches)

Forgings for each type of component were made by the following alloy/processing systems.

Aluminum Alloy	Processing
7075	T73 Commercial Alloy
7149	ITMT
7475	ITMT

Commercial 7075-T73, 7475, and 7149 aluminum alloy forgings were procured for each of the components. Processing by ITMT was accomplished on the 7475 and 7149 materials prior to the production die forging operation and in such a manner that the production forging operations could be utilized without modification to complete the forgings. A total of 66 forgings were procured.

TASK VI FABRICATE DYNAMIC COMPONENTS

During Task VI, all components were manufactured by current production methods and according to current drawing specifications. A total of 48 complete component assemblies were fabricated.

TASK VII CONDUCT TESTS ON DYNAMIC COMPONENTS

Fatigue properties and damage tolerance properties of the helicopter dynamic system components fabricated from the various alloy/processing combinations were determined by test. Fatigue strength properties were established for both the bellcrank assembly and the drive scissors arm assembly. Typically, these bench fatigue tests were conducted under constant amplitude loading which developed data over the cyclic life range from 1×10^5 to 5×10^7 cycles. A total of 36 full-scale components were bench fatigue tested.

Where practical, damage tolerance data was also obtained, this was accomplished by measuring the fatigue crack growth in certain of the components subsequent to the initiation and detection of the initial cracking.

As part of the intial program, it was proposed that additional damage tolerance information in the form of ballistic impact resistance be evaluated. The procuring agency was to coordinate the implementation of the actual ballistics testing. At the time of preparation of this report, the ballistic testing had not been completed and, therefore, no ballistic impact resistance data is presented in this report.

TASK VIII ANALYZE AND EVALUATE DATA

The objectives of this task were the analysis and evaluation of the mechanical properties data developed in the previous task and the assessment of the impact of any demonstrated improved mechanical properties on the weight and cost of helicopter components.

The influence of processing on properties was to be identified with primary emphasis placed on ranking the processing techniques with respect to their capability to improve fatigue and damage tolerance resistance properties. The properties obtained from the conventionally processed 7075-T73 forgings were compared with the properties exhibited by the forgings fabricated by the advanced alloy/process combinations.

Each of these four tasks is discussed in detail in the following sections of this report.

TASK V PROVIDE PRODUCTION FORGINGS

The primary objective of this task was the processing of forgings for two typical types of helicopter components utilizing both conventional techniques and advanced techniques, the latter to produce a fine-grained recrystallized structure associated with improvements in certain mechanical properties. In the discussion which follows, information is presented relative to the components, the general processing background, and the specific details relative to the materials utilized and the procedures by which they were processed.

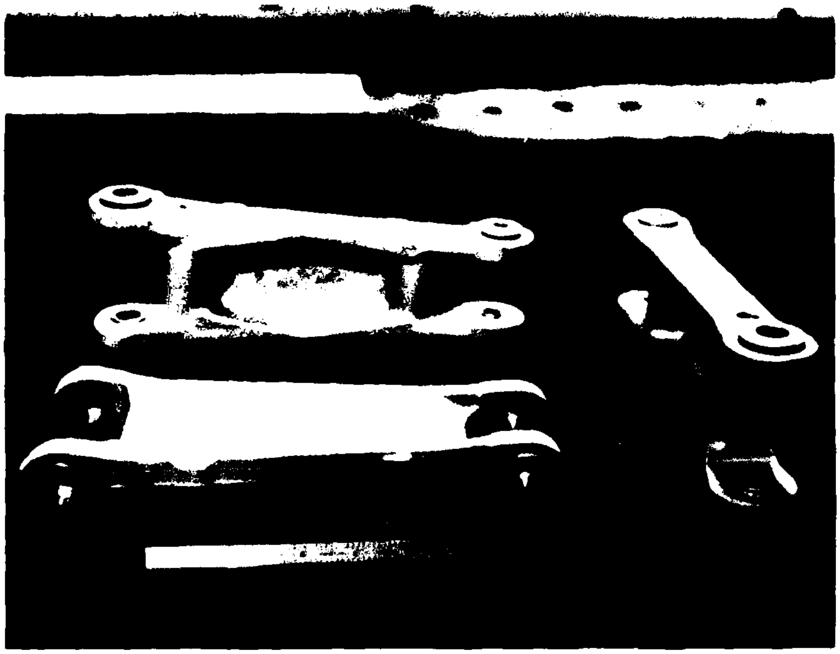
COMPONENTS

Two types of helicopter dynamic system components were selected as vehicles for evaluating the potential of the advanced processing for improving mechanical properties. The two components are the lateral differential bellcrank assembly and the drive scissors arm assembly. The drawings defining the geometry of these components and their general characteristic thicknesses are summarized below.

Component Description	Drawing Numbers Defining Component Geometry (Drawings contained in Appendix)		Forging Nominal Thickness Dimension (mm)
	Basic Detailed Geometry	Modification for Test Program	
Drive Scissors Arm Assembly	107R3598	SK27177	13 to 51 (0.5 to 2.0 inches)
Lateral Differential Bellcrank Assembly	107C2652	SK27176	51 to 76 (2.0 to 3.0 inches)

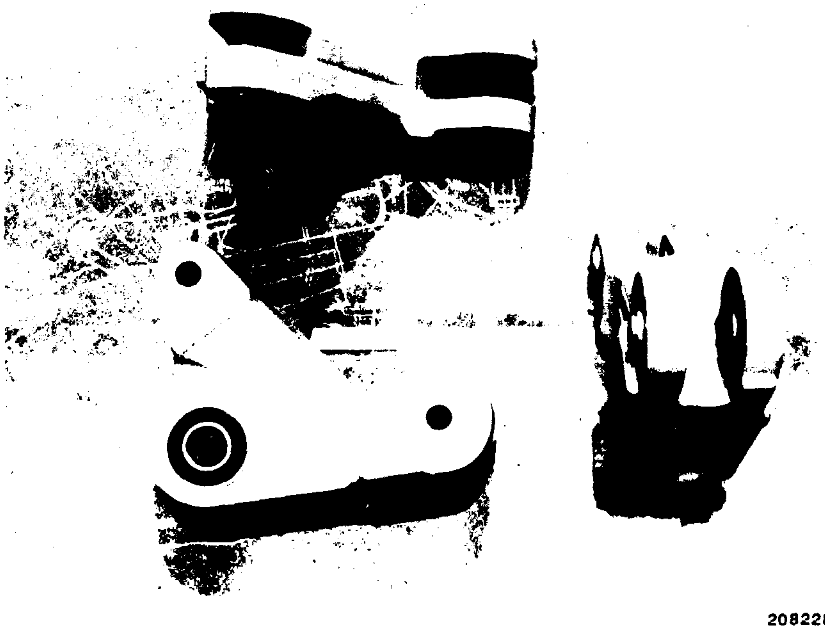
Photographs of each of these components are shown in Figures 1 and 2. Both components are located in the helicopter control system. Figures 3 and 4 show the locations of these components with respect to the helicopter rotor control system. These components are considered flight critical since failure of one of these components could possibly lead to loss of the aircraft. The governing mode of loading which controlled the structural design of these components was fatigue. At the time of the writing of this report, these components are fabricated from 2014-T6 aluminum alloy forgings and utilized successfully on the H-46 series helicopters built by the Boeing Vertol Company. The components were selected for evaluation of other alloy/processing combinations for the following reasons.

- The components are typical of a wide range of military and commercial helicopter parts fabricated from aluminum forgings.
- The component geometries encompass a range of thicknesses, thereby permitting a more comprehensive evaluation of the processes.
- The dies and tooling for the components were available.



C38287

Figure 1. Drive Scissors Arm Assembly



208228

Figure 2. Lateral Differential Bellcrank Assembly

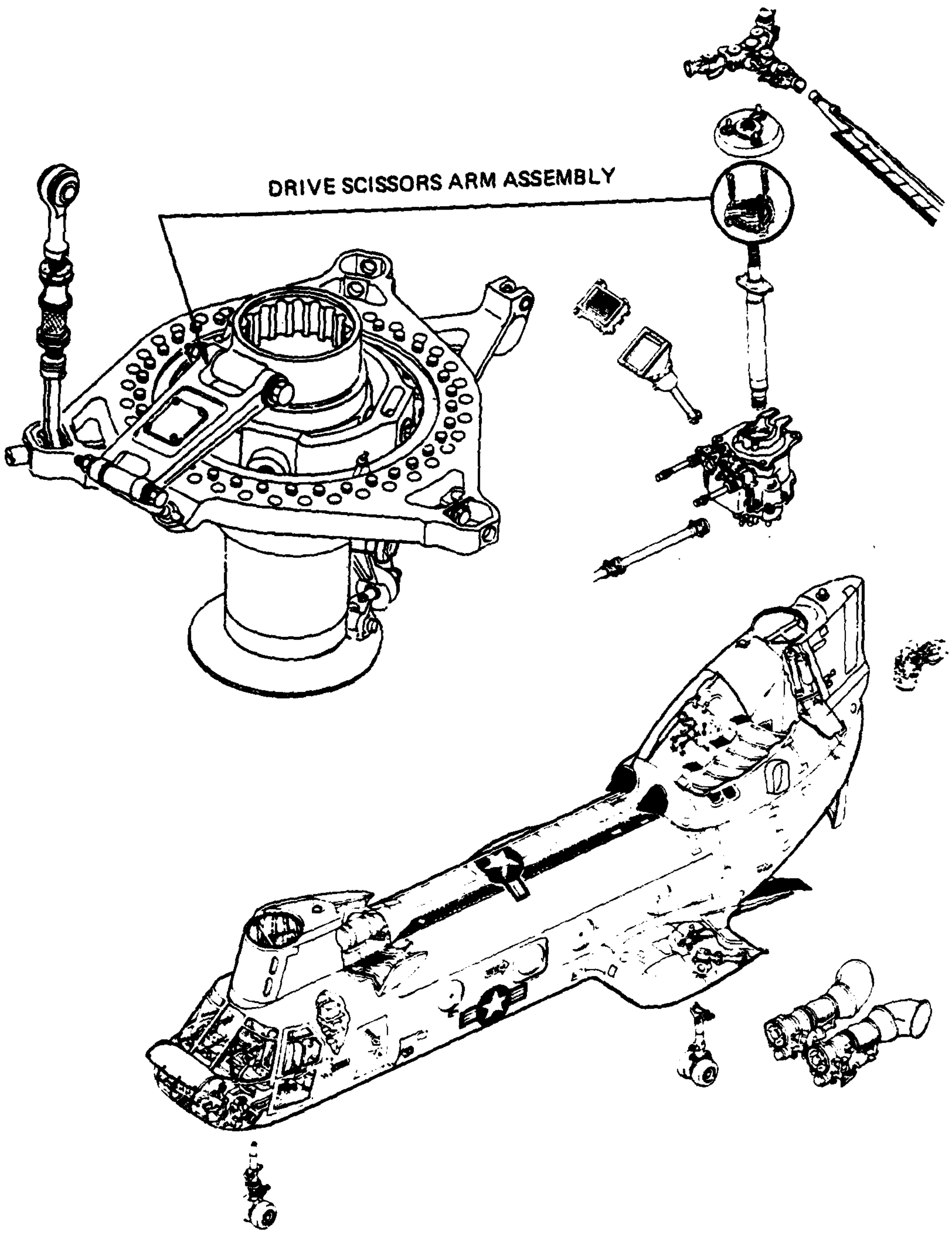


Figure 3. Location of Drive Scissors Arm Assembly With Respect to Helicopter Rotor Control System

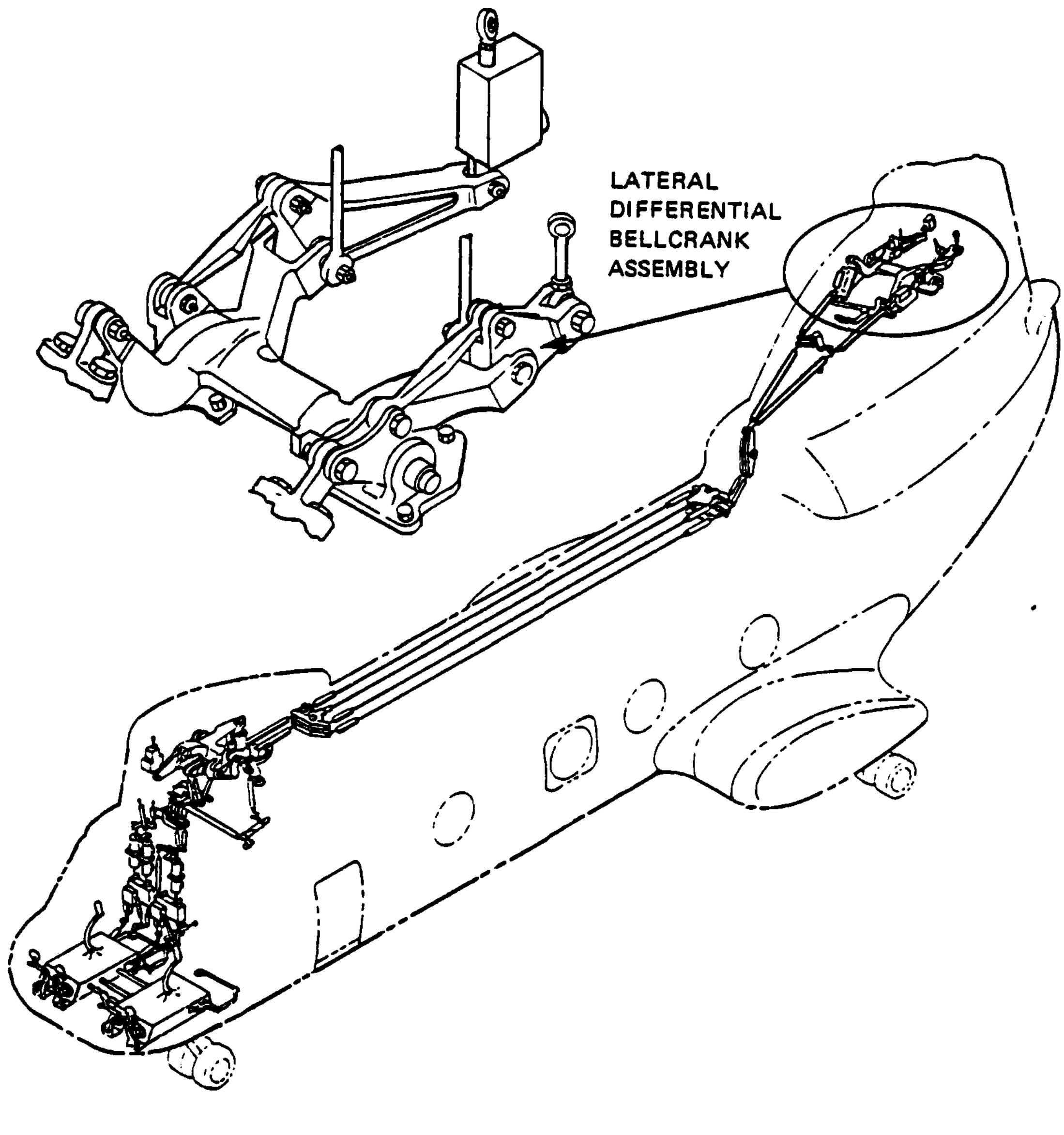


Figure 4. Location of Lateral Differential Bellcrank Assembly with Respect to Helicopter Rotor Control System

- Basic fatigue test data for the components exist and provide baseline information with which subsequent data can be compared.
- The manner of fatigue failure in test of the two types of components could differ, thereby providing additional information on which to evaluate the processes. (This item is discussed in detail under Task VIII, Analyze and Evaluate Data.)

PROCESSING BACKGROUND

Intermediate thermal-mechanical treatments are processes designed to produce a fine-grained recrystallized structure favorable for high fracture toughness. Originally, ITMT processes were developed for 7XXX Series aluminum alloy plate. As part of an earlier program described in Reference 1, it was demonstrated that similar processes were commercially feasible for hand forgings. Basically, this was achieved by first forging the ingot in the conventional manner and then forging at lower-than-conventional temperatures to introduce a high degree of strain hardening. The forgings then were given a high temperature thermal treatment during which the high degree of strain hardening promoted recrystallization to a relatively fine-grained, equiaxed structure.

In the program described herein, the most promising ITMT process, developed under the previous program of Reference 1, was used to prepare hand-forged forging stock. Appropriate size billets were machined from the ITMT forge stock. The billets were then die forged into two helicopter components using standard commercial die forging practices. The two components also were produced as conventional 7075-T73 die forgings for comparison.

MATERIAL AND PROCEDURE

Alloys

Two alloys, 7475 and 7149, were evaluated for response to ITMT processing. Alloy 7475 is a high purity modification of 7075 developed to provide high fracture toughness. At present it is produced commercially only in the form of rolled sheet and plate. Alloy 7049 was developed to provide better strength than 7075.

Alloy 7149 is a high-purity version of 7049 to promote better fracture toughness.

Ingot

Direct chill ingots 457mm (18 inches) in diameter were cast in alloys 7475 and 7149. The ingots were homogenized using their respective commercial preheat treatments. Following this, they were scalped and sawed to a 365mm (14 inches) diameter by 660mm (26 inches) length for fabrication into ITMT forging stock. Preheating and all subsequent thermal operations were preformed in circulating air furnaces.

Fabrication

Forging Stock

The ITMT hand forged stock was produced using the practices detailed in Table 1. The operation is shown schematically in Figure 5.

Forging operations II-A through II-D were performed at conventional forging temperatures and represent a kneading type operation which has the objective of producing a thoroughly worked forged structure. Operations II-E through II-G are the intermediate thermomechanical operations that produce the fine grained, highly recrystallized structure; while operation II-H is merely a final sizing operation.

The finished ITMT forged slabs were sonic inspected to MIL-I-8908l Class A standards and the required number of blanks were taken from sound areas.

Round 64mm (2.5 inches) 7075-F forged rod, purchased from a warehouse distributor, was used as stock for the conventional die forgings.

Die Forgings

Two die forged shapes were produced:

- Lateral differential bellcrank, Boeing Vertol Company Part Number 107C2652-F, Drawing Number SK27176, forged by Alcoa-Cleveland Works on Die Number 14893.
- Drive scissors arm, Boeing Vertol Company Part Number 107R3598-F3, Drawing Number SK27177, forged by the D.L. Auld Company.

Conventional die forging practices were used to produce 12 pieces of each shape in alloys 7149 and 7475 and 15 pieces of each shape in alloy 7075. The practice used by ALCOA consisted of two operations in the finish die (there is no blocker die) at 416°C (780°F). Each forging was penetrant inspected and met the requirements of MIL-I-6866B2, Type I, Method A.

All the F Temper forgings were heat treated to the T73 temper at ALCOA Laboratories using the practices listed in Table 2.

One piece of each die forging was destructively tested to obtain remelt-chemical composition, electrical conductivity and tensile properties of a specimen taken perpendicular to the parting plane. The results of these quality control tests are listed in Table 3. The chemical compositions are all well within the registered limits of the respective alloys. The electrical conductivity and tensile properties all exceed the minimum values required for 7075-T73.

Table 1. Fabrication Steps to Produce ITMT Forging Stock

	STEP	REFERENCE TO FIGURE 5	ALLOY	DESCRIPTION OF FABRICATION STEP
STARTING MATERIAL	1	-	ALL	SCALPED AND PREHEATED 265MM DIAMETER BY 660MM LONG (14 x 26 INCHES) 7149 AND 7475 INGOT SECTIONS. INGOTS PREHEATED USING STANDARD COMMERCIAL PRACTICES.
FORGING OPERATIONS	II A	-	ALL	HEAT TO 413°C (775°F)
	II B	- (1) (2) (3)	ALL	FORGE AT 413 TO 340°C (775 TO 650°F) AS FOLLOWS DRAW TO 279 x 279 x 838MM (11 x 11 x 33 INCHES) "A" UPSET AND DRAW TO 318 x 318 x 660MM (12.5 x 12.5 x 26 INCHES) "B" UPSET AND DRAW TO 318 x 318 x 660MM (12.5 x 12.5 x 26 INCHES)
	II C	-	ALL	REHEAT TO 413°C (775°F)
	II D	- (4)	ALL	FORGE AT 413°C TO 340°C (775 TO 650°F) "A" UPSET AND DRAW TO 292 x 292 x 762MM (11.5 x 11.5 x 30 INCHES)
	II E	-	 7149 7475	ANNEAL 2 HOURS AT 471 to 460°C (880 TO 860°F), COOL TO 413°C (775°F) 2 HOURS AT 413 TO 401°C (775 TO 755°F), COOL TO 260°C (500°F) 4 HOURS AT 260 TO 249°C (500 TO 480°F) 2 HOURS AT 516 TO 504°C (960 TO 940°F), COOL TO 413°C (775°F) 2 HOURS AT 413 TO 401°C (775 TO 755°F), COOL TO 260°C (500°F) 4 HOURS AT 260 TO 249°C (500 TO 480°F)
	II F	- (5)	ALL	FORGE AT 230 TO 204°C (450 TO 400°F) "B" UPSET AND DRAW TO 99 x 397 x 1651MM (3.9 x 15.6 x 65 INCHES) NOTE: THE HANDFORGED SLABS OF BOTH ALLOYS INCURRED CONSIDERABLE CRACKING DURING THE 230 TO 204°C FORGING OPERATION. CONSEQUENTLY THE SLABS WERE SONIC INSPECTED AT THIS STAGE AND THE CRACKED AREAS REMOVED BY SAWING BEFORE PROCEEDING WITH FURTHER PROCESSING.
	II G	-	 7149 7475	RECRYSTALLIZE 10 HOURS AT 460 TO 471°C (860 TO 880°F), AIR COOL 10 HOURS AT 504 TO 516°C (940 TO 960°F), AIR COOL
	II H	- (6)	ALL	FINISH FORGE AT 413 TO 340°C (775 TO 650°F) DRAW TO 70MM (2.75 INCHES) THICK HANDFORGED SLAB
	II I	-	ALL	SAW 24 BLANKS OF EACH ALLOY, SAWED SIZE 70 x 70 x 280MM LONG (2.75 x 2.75 x 11-INCHES LONG)
	II J	-	ALL	MACHINE BLANKS TO 70MM DIAMETER BY 280MM LONG (2.75-INCHES DIAMETER BY 11-INCHES LONG) BILLETS FOR DIE FORGING

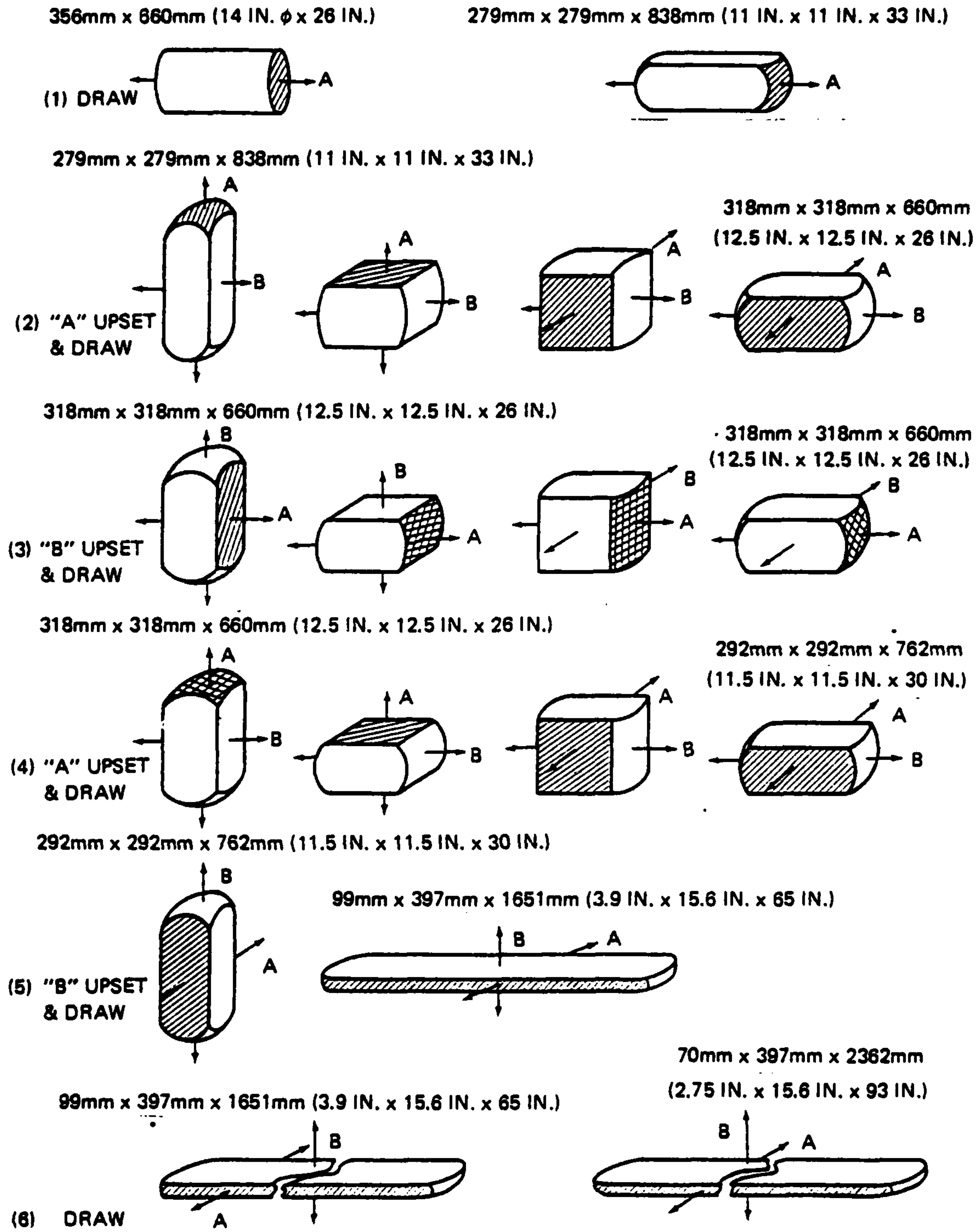


Figure 5. Forging Sequences Used to Produce 70mm x 397mm x 2362mm (2.75 IN. x 15.6 IN. x 93 IN.) 7149 and 7475 ITMT Hand Forgings

Table 2. Solution Heat-Treat, Quench and Aging Practices

PROCESS	ALLOY	PRACTICE
SOLUTION HEAT TREAT	7075-T73 7475-T73 7149-T73	4 HOURS AT 471°C (880°F) 4 HOURS AT 516°C (960°F) 4 HOURS AT 466°C (870°F)
QUENCH	ALL	QUENCH IN WATER AT 25°C (77°F)
NATURAL AGE	ALL	FOUR DAYS AT AMBIENT ROOM TEMPERATURE
ARTIFICIAL AGING	7075-T73	4 HOURS AT 121°C (250°F) PLUS 7.5 HOURS AT 177°C (350°F)
	7475-T73	4 HOURS AT 121°C (250°F) PLUS 9 HOURS AT 177°C (350°F)
	7149-T73	4 HOURS AT 121°C (250°F) PLUS 8 HOURS AT 177°C (350°F)
	NOTE: FOR THE SECOND STEP 177°C (350°F) AGE, A 3 HOUR HEAT UP RATE WAS USED, FOLLOWED BY ALCOA 420 PRACTICE INTEGRATOR AGING	

Table 3. Properties of Forging Materials

Chemical Compositions of the Three Forging Stock Alloys

ALLOY	REMELT COMPOSITION BY ELEMENT, PERCENT									
	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Be
7075	0.08	0.18	1.52	0.02	2.50	0.22	0.00	5.62	0.02	0.001
7475	0.04	0.05	1.69	0.00	2.23	0.22	0.00	5.66	0.03	0.000
7149	0.05	0.12	1.57	0.00	2.59	0.15	0.00	7.80	0.03	0.002

Electrical Conductivities and Tensile Properties of the Six T73 Temper Die Forgings

TYPE OF FORGING	ALLOY	S. NUMBER	ELECTRICAL CONDUCTIVITY PERCENT IACS	TENSILE PROPERTIES PERPENDICULAR TO PARTING PLANE		
				TENSILE STRENGTH MPa (KSI)	YIELD STRENGTH MPa (KSI)	ELONGATION PERCENT IN 4D
	7075-T73	SK27176-2F	41.0	485 (70.4)	412 (59.8)	6.2
BELLCRANK	7475-T73	SK27176-4F	40.6	488 (70.8)	418 (60.6)	7.8
	7149-T73	SK27176-6F	40.9	501 (72.7)	421 (61.0)	9.4
DRIVE	7075-T73	SK27177-F11	40.5	494 (71.6)	434 (63.0)	8.6
SCISSORS	7475-T73	SK27177-F13	40.6	505 (73.2)	438 (63.5)	9.4
ARM	7149-T73	SK27177-F12	41.9	512 (74.2)	436 (63.3)	11.7
MINIMUM REQUIREMENTS FOR 7075-T73			38.0	425 (62.0)	365 (53.0)	3.0

TASK VI FABRICATE DYNAMIC COMPONENTS

Upon receipt of the die forgings for each of the types of components, fabrication proceeded in a manner identical to that utilized for production components. Eleven forgings were received for each alloy/component combination; a total of 66 forgings for the program. Eight forgings out of each group of eleven were then processed to final test specimen assemblies; the other three being held as contingency in the event of spoilage during machining or assembly. A total of 48 complete assemblies was provided.

The test specimen assemblies were fabricated according to the same manufacturing plan as the corresponding production components. The same tooling, machine settings, machining fluids, finishes and quality control/inspection parameters were utilized. Twenty-four drive scissors arm forgings were finish machined at the Boeing Company's Auburn, Washington facility. The bushings and bearings required to complete the assembly were installed at the Boeing Vertol Company. A sample of a complete drive scissors arm assembly is shown in Figure 1. Twenty-four bellcrank assemblies were fabricated by Southwest Manufacturing Inc., Wichita, Kansas. This contractor has been the source for machining and assembly of the production component. A sample of a complete lateral differential bellcrank assembly is shown in Figure 2.

TASK VII CONDUCT TESTS ON DYNAMIC COMPONENTS

Under this task, fatigue and damage tolerance testing was conducted on the two types of specimens. In the material which follows, the test setup, test procedures and test data associated with each of the components are discussed. All the testing described below was conducted at the Boeing Vertol Company Structural Testing Laboratory Facilities.

DRIVE SCISSORS ARM ASSEMBLY

A total of 18 drive scissors arm assembly specimens, six of each of three types of alloy/processing combinations, was bench fatigue tested.

Each specimen was installed in the test fixture which was designed to produce a manner of loading representative of that associated with the aircraft. The bench test setup with a specimen installed is shown in Figure 6. One end of the specimen was attached to a backstop via a simulated drive collar. Hardware representative of the aircraft was used to assemble the drive arm to the simulated drive collar. The backstop was mounted to a SF-IU Sonntag-Universal Fatigue Machine. The other end of the specimen was attached to a simulated drive link, again using representative hardware. The drive link was oriented at 65 degrees included angle with respect to the drive arm. This orientation is representative of a neutral control position on the helicopter. A strain gaged and calibrated load link provided the load input from the fatigue machine to the drive arm specimen via a universal rod end bearing and the simulated drive link.

The bench fatigue testing was conducted under constant amplitude loading conditions. At a given load condition, one of each of three types of specimens (7075, 7149, and 7475 aluminum alloys) was tested. Tests were conducted sequentially by load condition with each successive specimen being of a different alloy. The specimens were selected randomly. To minimize the number of test variables, all testing was conducted with the same test fixture on the same test machine. The same personnel were responsible for conducting the entire series of tests. New attaching hardware was utilized with each specimen. The attaching bolts were lubricated with molydenum disulfide grease and torqued to consistent values. The loading was controlled via the calibrated strain-gaged load link and further checked by machine setting and machine platen deflection. The steady and alternating loads were measured by an Ellis Associates Model BA-13 Bridge Amplifier as displayed on an oscilloscope. The test fatigue load frequency was a constant 30 Hertz. The testing was accomplished in a laboratory air environment at ambient room temperature during the time period from 25 October 1978 to 28 April 1979.

The data resulting from the bench fatigue tests of the drive scissors arm assemblies is summarized in Table 4. Typical modes of failure of these test specimens are shown in Figures 7 through 9.

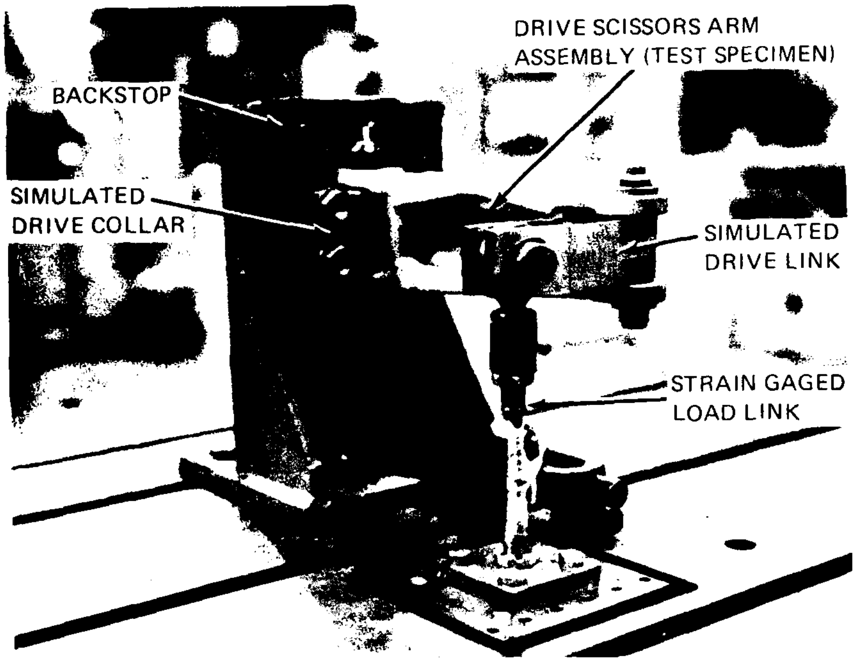


Figure 6. Drive Scissors Arm Assembly, Bench Fatigue Test Setup

Table 4. Summary of Test Data From Bench Fatigue Tests of Drive Scissors Arm Assemblies

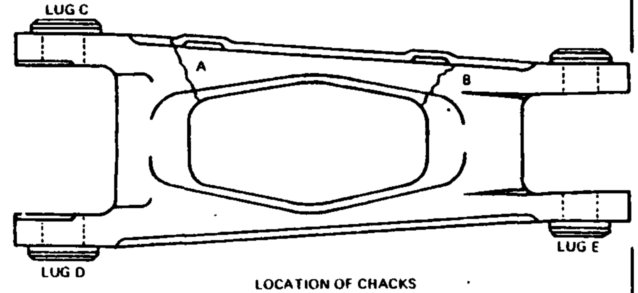
TEST DATE		SPECIMEN SK 27177 DESCRIPTION		Bolt Torque, Newton-Meter (Inch-Lb)		APPLIED LOAD NEWTONS (LB)		CYCLES x 10^6	REMARKS
				16mm (5/8 IN.) BOLT	11mm (7/16 IN.) BOLT				
START	END	NO.	ALLOY/CONDITION						
10-25-78	12-14-78	1	7075-T73	28.2 [2] (250)	28.2 [3] (250)	2669 ± 2669	(600 ± 600)	2.372	FAILURE: CRACK SIMILAR TO LOCATION A
12-08-78	12-08-78	1	7475-T73 ITMT	27.1 (240)	28.2 (250)	2669 ± 2669	(600 ± 600)	0.169	FAILURE: CRACK SIMILAR TO LOCATION B
10-28-78	12-13-78	1	7149-T73 ITMT	28.2 [2] (250)	28.2 [3] (250)	2669 ± 2669	(600 ± 600)	15.232	RUNOUT
12-14-78	12-14-78	2	7075-T73	33.9 (300)	28.2 (250)	2891 ± 2891	(650 ± 650)	0.235	FAILURE: CRACK SIMILAR TO LOCATION B
12-15-78	12-15-78	2	7475-T73 ITMT	33.9 (300)	28.2 (250)	2891 ± 2891	(650 ± 650)	0.456	FAILURE: CRACK THROUGH LUG C
12-14-78	12-14-78	2	7149-T73 ITMT	33.9 (300)	28.2 (250)	2891 ± 2891	(650 ± 650)	0.108	FAILURE: CRACK THROUGH LUG C
12-18-78	12-20-78	3	7075-T73	33.9 (300)	28.2 (250)	2780 ± 2780	(625 ± 625)	3.058	FAILURE: CRACK SIMILAR TO LOCATION B
01-02-79	01-02-79	3	7475-T73 ITMT	28.2 (250)	28.2 (250)	2780 ± 2780	(625 ± 625)	0.130	FAILURE: CRACK SIMILAR TO LOCATION B
12-20-78	12-21-78	3	7149-T73 ITMT	28.2 (250)	28.2 (250)	2780 ± 2780	(625 ± 625)	2.321	FAILURE: CRACK THROUGH LUG D
12-21-78	12-21-78	4	7075-T73	28.2 (250)	28.2 (250)	2447 ± 2447	(550 ± 550)	0.303	FAILURE: CRACK SIMILAR TO LOCATION B
01-03-79	01-08-79	4	7475-T73 ITMT	28.2 (250)	28.2 (250)	2447 ± 2447	(550 ± 550)	6.233	FAILURE: CRACK SIMILAR TO LOCATION A
01-08-79	01-19-79	4	7149-T73 ITMT	28.2 (250)	28.2 (250)	2447 ± 2447	(550 ± 550)	30.000	RUNOUT
01-22-79	02-10-79	5	7075-T73	28.2 (250)	28.2 (250)	2224 ± 2224	(500 ± 500)	51.783	RUNOUT
02-11-79	03-05-79	5	7475-T73 ITMT	28.2 (250)	28.2 (250)	2224 ± 2224	(500 ± 500)	54.340	RUNOUT
03-06-79	03-19-79	5	7149-T73 ITMT	28.2 (250)	28.2 (250)	2224 ± 2224	(500 ± 500)	34.118	FAILURE: CRACK THROUGH LUG C
03-20-79	04-09-79	6	7075-T73	28.2 (250)	28.2 (250)	2447 ± 2447	(550 ± 550)	51.523	RUNOUT
04-17-79	04-28-79	6	7475-T73 ITMT	28.2 (250)	28.2 (250)	2447 ± 2447	(550 ± 550)	22.924	FAILURE: CRACK THROUGH LUG E
04-09-79	04-16-79	6	7149-T73 ITMT	28.2 (250)	28.2 (250)	2447 ± 2447	(550 ± 550)	15.986	FAILURE: CRACK THROUGH LUG D

NOTES: 1. TEST LOADS APPLIED AT 30 HERTZ IN AIR ENVIRONMENT AT AMBIENT ROOM TEMPERATURE.

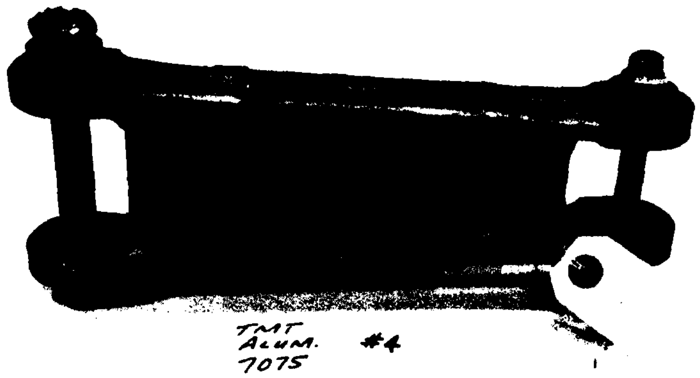
[2] INITIAL TORQUE VALUE 19.8 NEWTON-METER (175 INCH-LB) INCREASED DURING TEST TO 28.2 NEWTON-METER (250 INCH-LB) TO PREVENT BUSHING FLANGE FAILURES.

[3] INITIAL TORQUE VALUE 16.9 NEWTON-METER (150 INCH-LB) INCREASED DURING TEST TO 28.2 NEWTON-METER (250 INCH-LB) TO PREVENT BUSHING FLANGE FAILURES.

4. BOLTS TORQUED WITH THREADS LUBRICATED

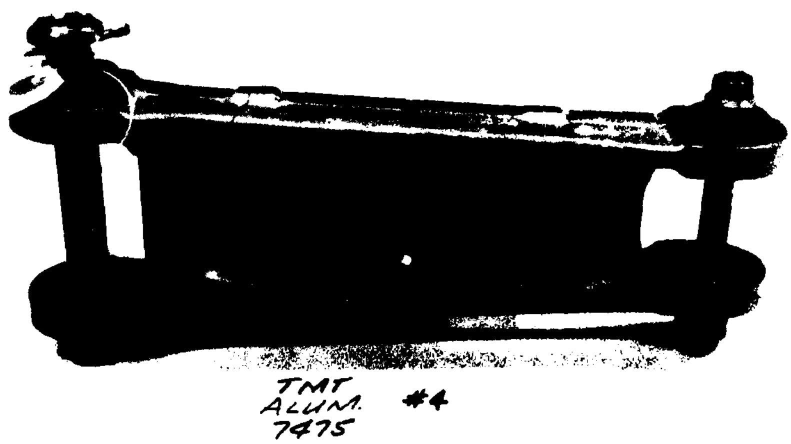


LOCATION OF CHACKS



C36700

Figure 7. Failure Mode Exhibited by Drive Scissors Arm Assembly, Fatigue Test Specimen Number 4 of 7075-T73 Material



C36699

Figure 8. Failure Mode Exhibited by Drive Scissors Arm Assembly, Fatigue Test Specimen Number 4 of 7475-T73 ITMT Material

Damage tolerance data was not obtained on these specimens since the crack extension at the time of failure detection was too great. Meaningful comparative data could not be practically obtained in the short remaining crack propagation life. In addition, these specimens exhibited a number of different modes/locations of failure which would not allow a simple direct comparison of the damage tolerance characteristics of the three material systems.

LATERAL DIFFERENTIAL BELLCRANK ASSEMBLY

A total of 18 lateral differential bellcrank assembly specimens, six of each of three types of alloy/processing combinations, was bench fatigue tested.

Each specimen was installed in the test fixture which was designed to produce a manner of loading representative of that associated with the aircraft. The bench test setup with a specimen installed is shown in Figure 10. The load was applied to one set of lugs and reacted at the other two sets of lugs. The load application is through a simulated lateral link attachment point while the reactions simulate the rigid link and yoke attachment points in the control system assembly. The reactions are transferred to a backstop-type test fixture which is bolted to the test machine table. Hardware representative of the aircraft was used at the three attachment points associated with the test specimen. The specimen was oriented in a manner representative of a neutral control position on the helicopter. A strain gaged and calibrated load link provided the load input from the servo-controlled hydraulic fatigue test machine to the test specimen.

The bench fatigue testing was conducted under constant amplitude loading conditions. At a given load condition, one of each of three types of specimens (7075, 7149, and 7475 aluminum alloys) was tested. Tests were conducted sequentially by load condition with each successive specimen being of a different alloy. The specimens were selected randomly. To minimize the number of test variables, all testing was conducted with the same test fixture on the same test machine. The same personnel were responsible for conducting the entire series of tests. New attaching hardware was utilized with each specimen. The attaching bolts were lubricated with molydenum disulfide grease and torqued to consistent values. The loading was controlled via the calibrated strain gaged load link and further checked by monitoring pressure and deflection. The steady and alternating loads were measured by an Ellis Associates Model BA-13 Bridge Amplifier as displayed on an oscilloscope. The test fatigue load frequency was a constant 25 Hertz. The testing was accomplished in a laboratory air environment at ambient room temperatures during the time period from 15 October 1978 to 25 May 1979.

The data resulting from the bench fatigue tests of the lateral differentil bellcrank assemblies is summarized in Table 5.

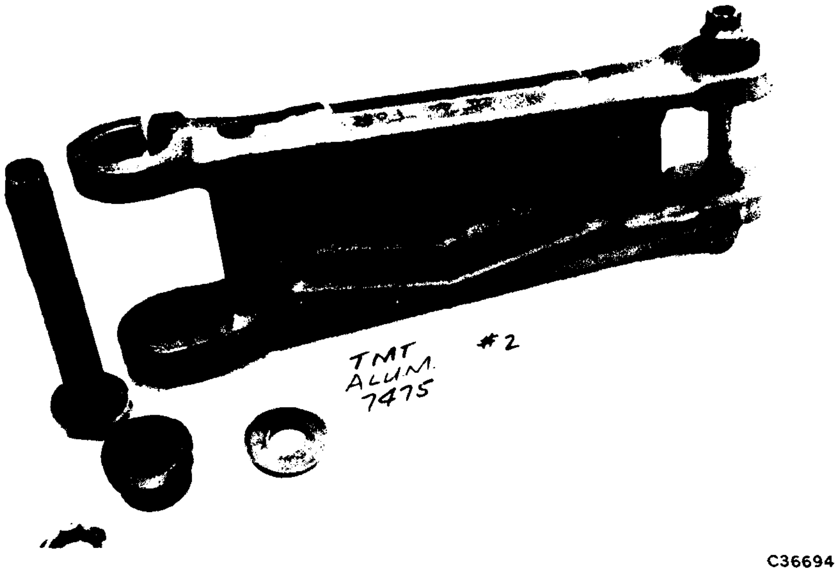


Figure 9. Failure Mode Exhibited by Drive Scissors Arm Assembly, Fatigue Test Specimen Number 2 of 7475-T73 ITMT Material

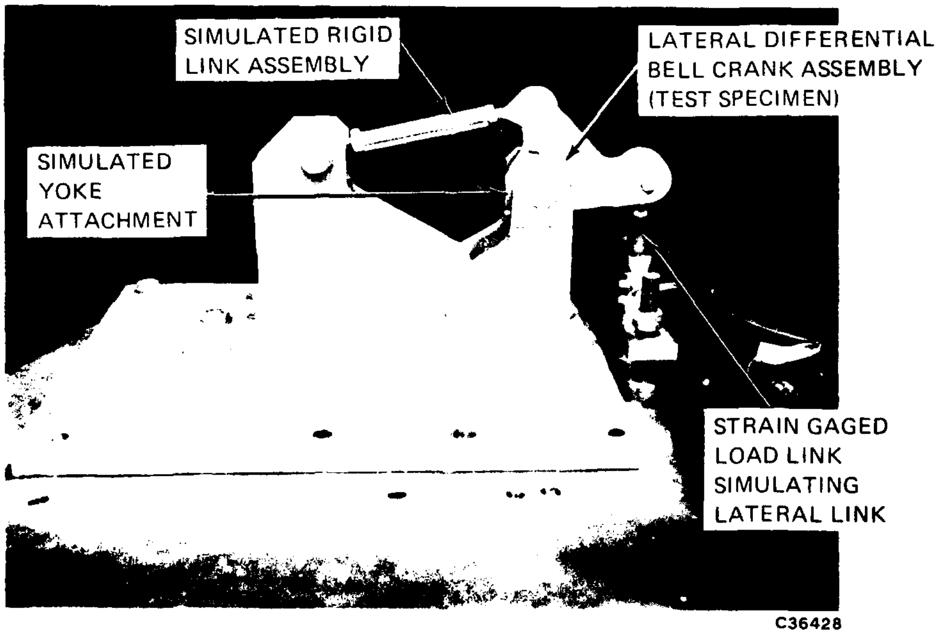
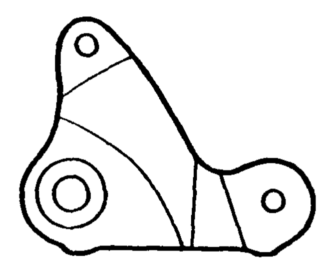


Figure 10. Lateral Differential Bellcrank Assembly, Bench Fatigue Test Setup

Table 5. Summary of Test Data From Bench Fatigue Tests of Lateral Differential Bellcrank Assemblies

TEST DATE START	TEST DATE END	SPECIMEN SK 27176 DESCRIPTION NO.	SERIAL NO.	ALLOY/CONDITION	APPLIED LOAD NEWTONS	APPLIED LOAD (LB)	CYCLES x 10^6	REMARKS
10-24-78	11-03-78	1	VU101	7075-T73	3688 ± 10231	(829 ± 2300)	5.045	RUNOUT
10-15-78	10-23-78	1	VU103	7475-T73 ITMT	3688 ± 10231	(829 ± 2300)	5.036	RUNOUT
11-13-78	11-15-78	1	VU105	7149-T73 ITMT	3688 ± 10231	(829 ± 2300)	5,062	RUNOUT
11-06-78	11-06-78	1	VU101	7075-T73	4609 ± 12789	(1036 ± 2875)	0.144	FAILURE, CRACKING OF ONE LUG AT A
11-07-78	11-13-78	1	VU103	7475-T73 ITMT	4609 ± 12789	(1036 ± 2875)	3.188	FAILURE, CARACKING OF ONE LUG AT A
11-15-78	11-16-78	1	VU105	7149-T73 ITMT	4609 ± 12789	(1036 ± 2875)	1,736	FAILURE, CRACKING OF ONE LUG AT A
11-17-78	11-28-78	2	VU107	7075-T73	4328 ± 12011	(973 ± 2700)	8,244	FAILURE, CRACKING OF ONE LUG AT A SECONDARY CRACKING OF LUG AT C
11-28-78	12-05-78	2	VU107	7475-T73 ITMT	4328 ± 12011	(973 ± 2700)	8.230	FAILURE, CRACKING OF ONE LUG AT A
12-05-78	12-12-78	2	VU101	7149-T73 ITMT	4328 ± 12011	(973 ± 2700)	4.743	FAILURE, CRACKING OF ONE LUG AT A AND ONE LUG AT B
12-19-78	01-07-79	3	VU104	7075-T73	5129 ± 14235	(1153 ± 3200)	6.241	FAILURE, CRACKING OF ONE LUG AT A AND ONE LUG AT B
01-12-79	01-13-79	3	VU104	7475-T73 ITMT	5129 ± 14235	(1153 ± 3200)	1.811	FAILURE, CRACKING OF ONE LUG AT A AND ONE LUG AT B
01-15-79	01-22-79	3	VU107	7149-T73 ITMT	5129 ± 14235	(1153 ± 3200)	2.867	FAILURE, CRACKING OF ONE LUG AT A AND TWO LUGS AT B
01-25-79	01-31-79	4	VU106	7075-T73	4008 ± 11121	(901 ± 2500)	8.184	FAILURE, CRACKING OF ONE LUG AT A
02-06-79	02-12-79	4	VU105	7475-T73 ITMT	4008 ± 11121	(901 ± 2500)	6.180	FAILURE, CRACKING OF ONE LUG AT A
02-13-79	02-21-79	4	VU102	7149-T73 ITMT	4008 ± 11121	(901 ± 2500)	8.060	FAILURE, CRACKING OF ONE LUG AT A
02-22-79	04-02-79	5	VU103	7075-T73	3688 ± 10231	(829 ± 2300)	56.441	FAILURE, CRACKING OF ONE LUG AT B SECONDARY CRACKING OF LUG AT C
04-02-79	04-20-79	5	VU102	7475-T73 ITMT	3688 ± 10231	(829 ± 2300)	32.319	FAILURE, CRACKING OF ONE LUG AT A AND ONE LUG AT B
04-23-79	05-07-79	5	VU106	7149-T73 ITMT	3688 ± 10231	(829 ± 2300)	25.287	FAILURE, CRACKING OF ONE LUG AT B
05-08-79	05-15-79	6	VU102	7075-T73	3848 ± 10676	(865 ± 2400)	9.108	FAILURE, CRACKING OF ONE LUG AT A
05-16-79	05-18-79	6	VU101	7475-T73 ITMT	3848 ± 10676	(865 ± 2400)	4.884	FAILURE, CRACKING OF ONE LUG AT A
05-21-79	05-25-79	6	VU104	7149-T73 ITMT	3848 ± 10676	(865 ± 2400)	5.930	FAILURE, CRACKING OF ONE LUG AT A

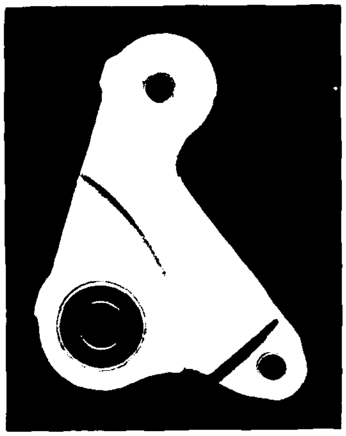
NOTES:
1. TEST LOAD APPLIED AT 25 HERTZ IN AIR ENVIRONMENT AT AMBIENT ROOM TEMPERATURE.
2. BOLTS TORQUED AT FOLLOWING VALUES:
   - LUG A 56.5 NEWTON-METER (500 INCH-LB)
   - LUG B 56.5 NEWTON-METER (500 INCH-LB)
   - LUG C 11.3 NEWTON-METER (100 INCH-LB)
3. BOLTS TORQUED WITH THREADS LUBRICATED.



INDEX FOR LOCATIONS

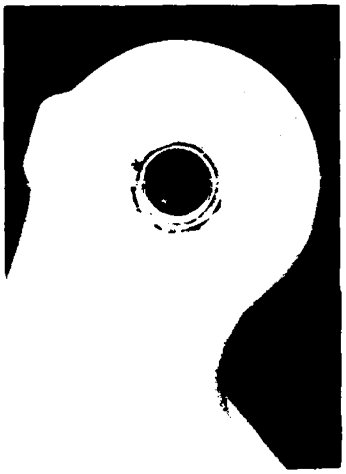
Various modes of failure of these test specimens are shown in Figures 11 through 14. Typically the cracks started at the interface between the aluminum lug bore and the bushing which is installed in the lug bore.

Damage tolerance information, in the form of fatigue crack growth data, was obtained on three bellcrank assembly specimens, one of each of the three alloy/processing combinations. The crack growth data was obtained utilizing the same test fixture and setup arrangement as that used for the basic fatigue testing. The fatigue crack growth testing setup is shown in Figure 15. The fatigue cracks were monitored visually and their length and the corresponding number of loading cycles were recorded. The cracks were monitored with the aid of a strobe light while the specimen was being dynamically loaded. Dye penetrant (Type MIL-I-25135, Spotcheck SLK-HF Penetrant by Magnaflux Corporation) was used as an aid in following the cracks. The resulting data is summarized in Table 6.



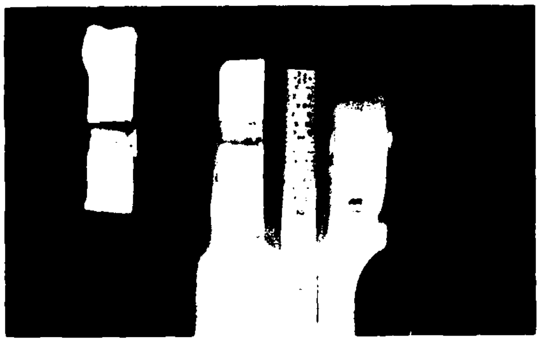
C36425

A. OVERALL VIEW OF TEST SPECIMEN AFTER FATIGUE TESTING



C36427

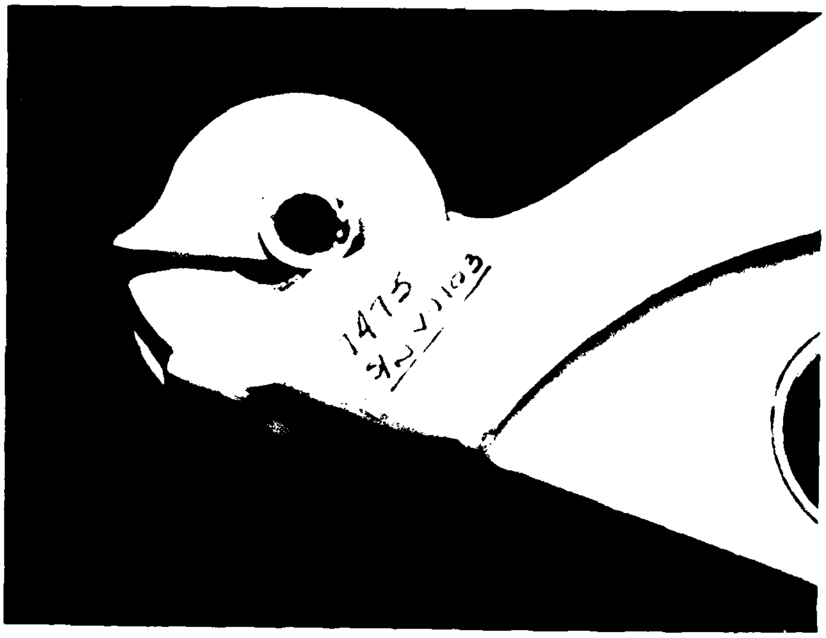
B. CLOSE-UP VIEW OF LUG WITH FATIGUE CRACK



C36426

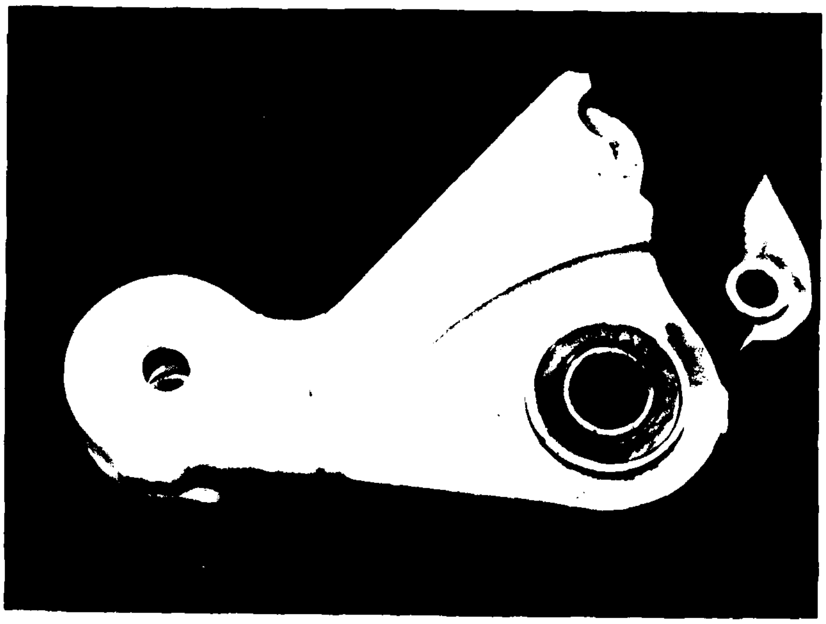
C. SECTIONAL VIEW OF LUG FRACTURE SURFACE

Figure 11. Failure Mode Exhibited by Lateral Differential Bellcrank Assembly, Fatigue Test Specimen Number 1 of 7075-T73 Material



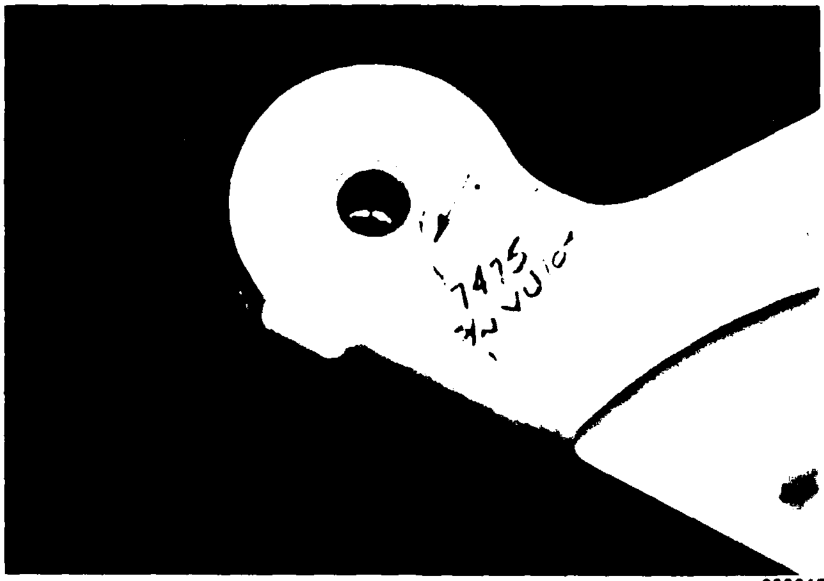
208246

Figure 12. Failure Mode Exhibited by Lateral Differential Bellcrank Assembly, Fatigue Test Specimen Number 1 of 7475-T73 ITMT Material



208241

Figure 13. Failure Mode Exhibited by Lateral Differential Bellcrank Assembly, Fatigue Test Specimen Number 2 of 7149-T73 Material



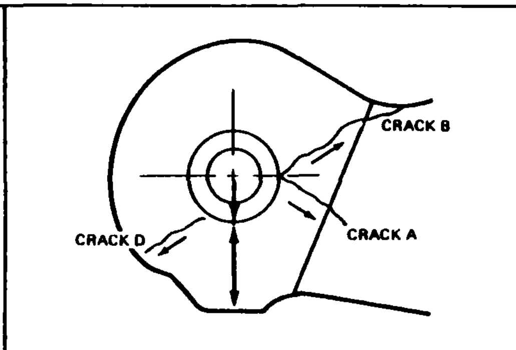
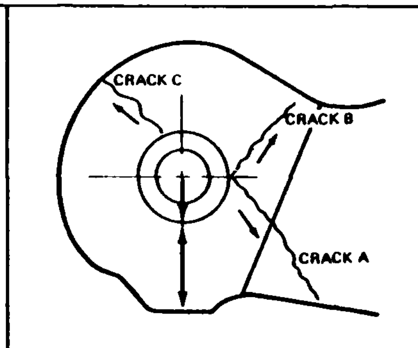
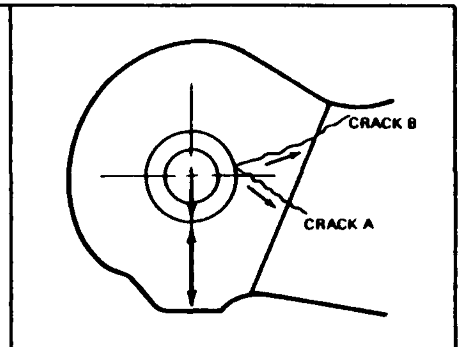
208247

Figure 14. Failure Mode Exhibited by Lateral Differential Bellcrank Assembly, Fatigue Test Specimen Number 4 of 7475-T73 ITMT Material

208229

Figure 15. Test Setup for Measuring Fatigue Crack Propagation Data on Lateral Differential Bellcrank Assembly

Table 6. Summary of Typical Fatigue Crack Growth Data Obtained From Testing Lateral Differential Bellcrank Assembly Specimens

PARAMETER			
			
MATERIAL	7075-T73	7475-T73 ITMT	7149-T73 ITMT
SERIAL NUMBER	VU 107	VU 107	VU 105
APPLIED LOAD	4328 ± 12011 NEWTONS (973 ± 2700 LBS)	4328 ± 12011 NEWTONS (973 ± 2700 LBS)	4328 ± 12011 NEWTONS (973 ± 2700 LBS)

Fatigue Crack Propagation Data (7075-T73, VU 107)

FATIGUE CYCLES	CRACK LENGTH, MM (INCH) CRACK A	CRACK B	CRACK D
6.056×10^6	- -	19.1 (0.75)	- -
7.163×10^6	- -	26.7 (1.05)	- -
7.890×10^6	- -	26.7 (1.05)	8.1 (0.32)
7.902×10^6	- -	26.7 (1.05)	- -
7.982×10^6	- -	26.7 (1.05)	8.6 (0.34)
8.135×10^6	- -	26.7 (1.05)	8.9 (0.35)
8.169×10^6	- -	26.7 (1.05)	9.1 (0.36)
8.217×10^6	11.4 (0.45)	26.7 (1.05)	9.4 (0.37)
8.219×10^6	11.4 (0.45)	26.7 (1.05)	9.4 (0.37)
8.235×10^6	12.7 (0.50)	26.7 (1.05)	9.4 (0.37)
8.244×10^6	12.7 (0.50)	26.7 (1.05)	9.4 (0.37)

Fatigue Crack Propagation Data (7475-T73 ITMT, VU 107)

FATIGUE CYCLES	CRACK LENGTH, MM (INCH) CRACK A	CRACK B	CRACK C
4.914×10^6	5.6 (0.22)	No Data	No Data
5.057×10^6	7.1 (0.28)		
5.397×10^6	13.2 (0.52)		
5.528×10^6	16.3 (0.64)		
5.808×10^6	18.5 (0.73)		
5.937×10^6	19.3 (0.76)		
5.979×10^6	19.8 (0.78)		
6.021×10^6	21.3 (0.84)		
7.431×10^6	21.3 (0.84)		
7.839×10^6	31.7 (1.25)		

Fatigue Crack Propagation Data (7149-T73 ITMT, VU 105)

FATIGUE CYCLES	CRACK LENGTH, MM (INCH) CRACK A	CRACK B
3.341×10^6	- -	10.2 (0.40)
3.351×10^6	- -	10.7 (0.42)
3.366×10^6	- -	11.4 (0.45)
3.386×10^6	- -	12.2 (0.48)
3.404×10^6	- -	12.7 (0.50)
3.437×10^6	- -	12.7 (0.50)
3.486×10^6	- -	13.2 (0.52)
3.579×10^6	- -	13.2 (0.52)
4.616×10^6	- -	19.8 (0.78)
5.021×10^6	- -	20.8 (0.82)
6.711×10^6	7.6 (0.30)	20.8 (0.82)
6.729×10^6	8.6 (0.34)	20.8 (0.82)
6.750×10^6	9.7 (0.38)	20.8 (0.82)

NOTES: 1. CRACK LENGTH MEASURED ON FACE OF LUG FROM THE POINT AT WHICH THE CRACK EMERGES FROM BEYOND THE WASHER.

2. LOADING APPLIED AT A FREQUENCY OF 25 HERTZ IN AN AIR ENVIRONMENT, AMBIENT ROOM TEMPERATURE.

TASK VIII ANALYZE AND EVALUATE DATA

The objectives of this task are to analyze and evaluate the test data developed in the previous tasks and to assess the impact on the weight and cost of helicopter components due to any improved mechanical properties which might be realized.

BENCH FATIGUE TEST DATA ANALYSIS

Several comparisons have been made based on the bench fatigue test data which was obtained on the drive scissors arm and bellcrank assemblies. The comparisons include:

- Relative fatigue strengths of the three alloy/processing combinations based on nominal data.
- Relative fatigue strengths of the three alloy/processing combinations considering failure modes.
- Relative fatigue strengths of the components and most applicable coupon data from Phase I of the program described in Reference 1.
- Relative fatigue strengths of the components tested in this program and previously tested components of the same configuration but of a different alloy.

Comparison of Nominal Data

Initial comparisons were made using the nominal data summarized in Tables 4 and 5. For each of the components, an L-N (Load versus number of cycles) plot of the bench fatigue test data was prepared.

The L-N data for the drive scissors arm assembly specimens is shown in Figure 16. The number of cycles to failure was established as that point where sufficient cracking or loss of stiffness had occurred to cause the specimen deflection to exceed a preset limit value which automatically shut off the fatigue test machine. Figures 7 through 9 show typical failure modes at the point of test machine shut off. As indicated previously, the test was arranged such that at each applied test load level, three specimens, one of each alloy/processing combination, were tested. The alloys of the specimens surviving for the longest and shortest number of cycles at each load level are summarized below:

Load Level Number (Arbitrarily in Descending Order)	Alloy of Specimen Surviving	
	Least No. of Cycles	Most No. of Cycles
1	7149-T73 ITMT	7475-T73 ITMT
2	7475-T73 ITMT	7075-T73
3	7475-T73 ITMT	7149-T73 ITMT
4	7075-T73	7075-T73
5	7149-T73 ITMT	N/A

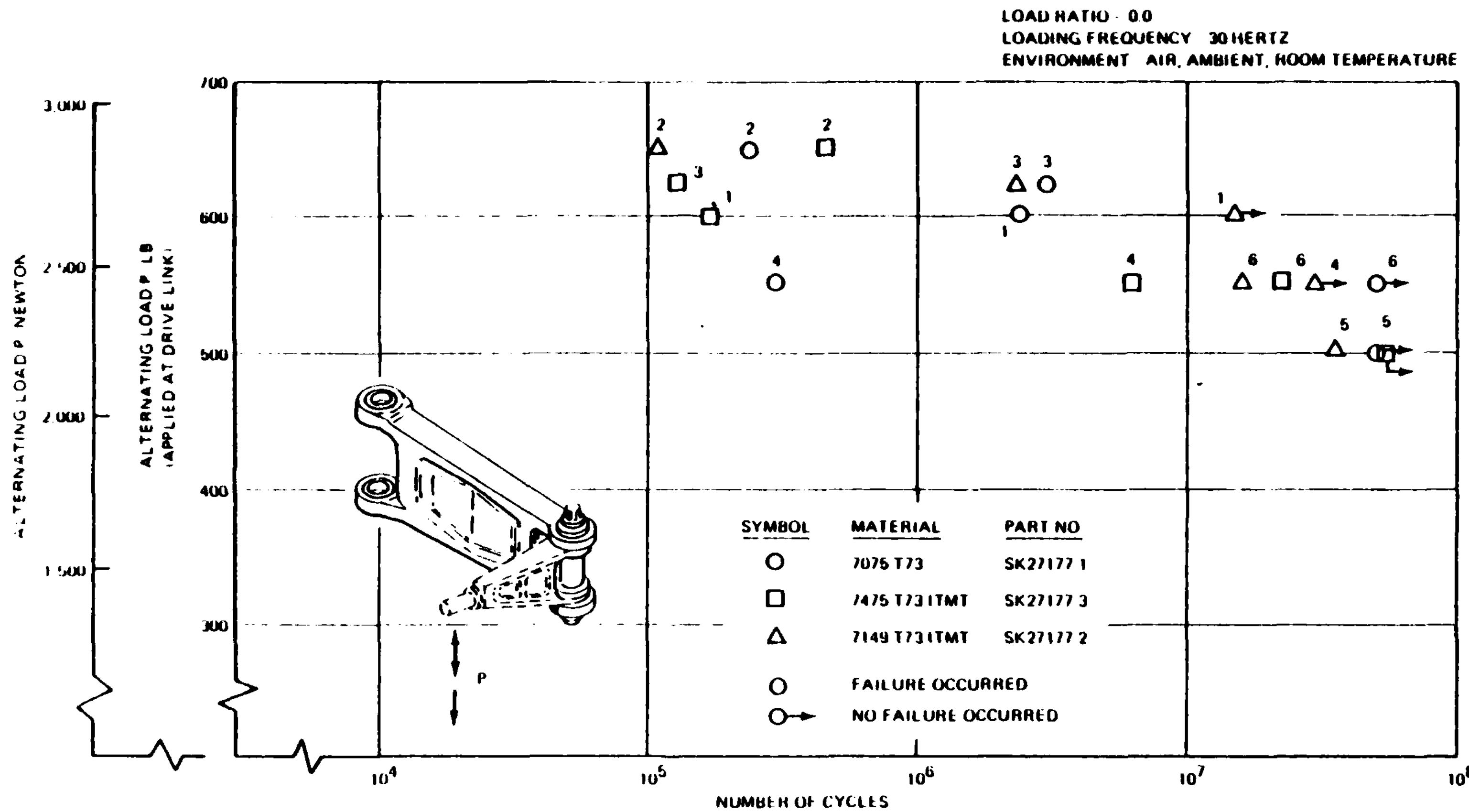


Figure 16. Plot of L-N Data for Drive Scissors Arm Assembly

A review of the above summary and the plot of Figure 16 indicates no significant differences in the fatigue strength performance of the three alloy/processing combinations based on the nominal data.

The L-N data for the lateral differential bellcrank assembly specimens is shown in Figure 17. The number of cycles to failure was established as that point at which cracking was first observed. Failures in these specimens occurred at lugs and the possibility for load sharing between the two lugs of the pair made it impractical to use deflection as a criterion for failure. Figures 11 through 14 show typical failure modes at the point of test completion. As described previously, a summary of the alloys of the specimens surviving for the longest and shortest number of cycles at each load level is shown below.

Load Level Number (Arbitrarily in Descending Order)	Alloy of Specimen Surviving	
	Least No. of Cycles	Most No. of Cycles
1	7475-T73 ITMT	7075-T73
2	7075-T73	7475-T73 ITMT
3	7149-T73 ITMT	7075-T73
4	7475-T73 ITMT	7075-T73
5	7475-T73 ITMT	7075-T73
6	7149-T73 ITMT	7075-T73

A review of the above summary and the plot of Figure 17 indicates that, generally, the 7075-T73 specimens are exhibiting longer fatigue life. However, a 7075-T73 specimen had one of the shortest fatigue lives. In view of this and the general scatter of data, it is concluded that the fatigue strength of any one of the alloy/processing combinations is not significantly superior to that of the others.

Comparison Based on Failure Modes

The second series of comparisons addresses the differences in failure modes. In general, the two types of components exhibited different failure modes. The failures of the drive scissors arm assembly specimens started at various locations with differing effective stress concentrations but without the influence of fretting. Fretting is defined as the phenomenon which takes place when two surfaces in contact experience slight repeated relative movement, even though the movement may be microscopic. In any case, the combined action of the fretting mechanism and repeated stress application results in fatigue damage (cracking) of a member. This damage is known as fretting fatigue. Note the design of the drive scissors arm assembly is such that the bushings at the attachment lugs are coated on the outside diameter with a non-metallic material which prevents fretting by eliminating the metal to metal contact between the steel bushing and the aluminum lug bore surface of the drive arm.

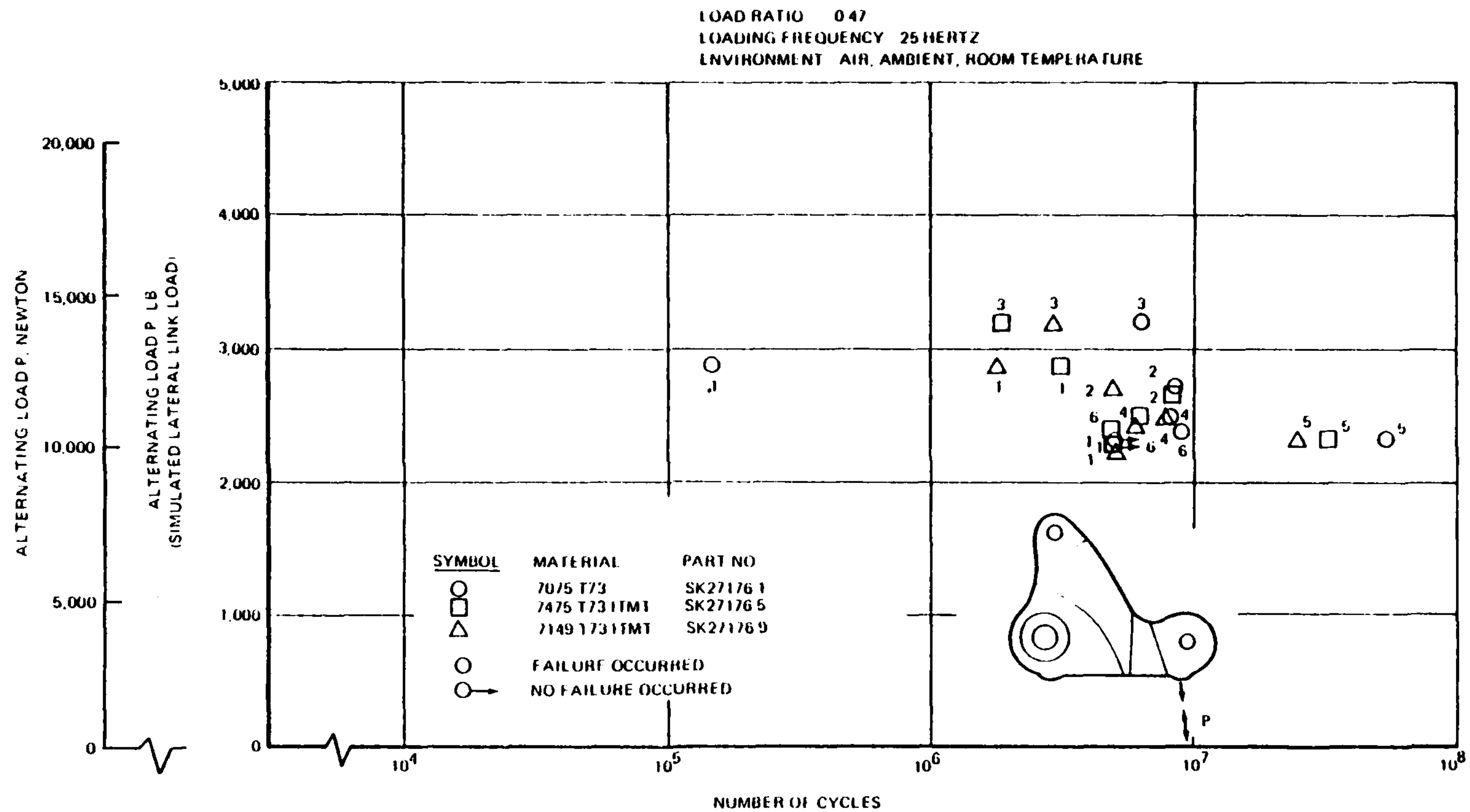


Figure 17. Plot of L-N Data for Lateral Differential Bellcrank Assembly

By contrast, the failures of the bellcrank assembly specimens were generally associated with fretting. The fretting originated at the lugs, involving the metal to metal interface between the outside surface of a steel bushing or bearing and the aluminum bellcrank. Thus, in general, the failures of the drive scissor arm could be catagorized as "notched (associated with a stress concentration) and unfretted", while those of the bellcrank could be catagorized as "notched and fretted".

In the case of the drive scissors arm assembly, a review of Table 4 indicates that somewhat more than one half the failures occurred in the basic body section of the arm as opposed to the lugs. Figure 18 shows a plot of L-N data for the body section only. In this case, it is seen that no body section failures occurred in specimens of the 7149-T73 ITMT material. The specimens of the 7475-T73 ITMT and 7075-T73 materials show almost the same average fatigue strength with respect to failures in the body section. The fatigue origins associated with the body section failures occurred at varied locations, such as section transitions, adjacent to tooling pads, or associated with part marking. Failures originating in the lug areas occurred only on the specimens of the 7149-T73 ITMT and 7475-T73 ITMT materials. Lug failures occurred most frequently in specimens of the 7149-T73 ITMT material.

For the lateral differential bellcrank assembly specimens, the predominant failure location was one of the lugs of lug pair A as indicated in Table 5. Figure 19 shows a plot of L-N data for the lug pair A location only. The differences between the plots of Figures 19 and 17 are minor and the initial conclusions hold.

Comparison of Component and Coupon Data

Figures 20 through 23 provide a general comparison of the relative fatigue performance of the 7075-T73 and 7475-T73 ITMT materials as coupon and as component specimens. Figures 20 and 21 were selected from Reference 1 as being the most applicable coupon fatigue data for comparison with the component data. The 7475-TMT 1 material cited in Figures 20 and 21 was determined to be optimally processed and that process was selected for the drive scissors arm and bellcrank component forgings of the 7475 and 7149 alloys. The coupon data is associated with a two-inch thick forging, roughly the size of the components which were tested. The coupon data is for stress concentration factors of 1.0 and 3.0. The stress concentrations associated with the components range from about 1.5 to somewhat greater than 3.0 depending on the particular failure location. In the case of the bellcrank failures which were associated with fretting, there is no direct comparison which can be made with the coupon data. The similarity of stress ratios for coupon and component data is quite close for the drive scissors arm assembly specimens (+0.05 vs 0.0) but only roughly comparable for the bellcrank specimens. In Figures 22 and 23, the component data are identical to Figures 16 and 17 respectively, except that the 7149 data has been removed and symbol changes have been made so that comparisons may be made with greater ease. Comparisons based on the relative fatigue strengths of the two alloy/processing combinations do not appear significantly different between coupons and components. The fact that the relative

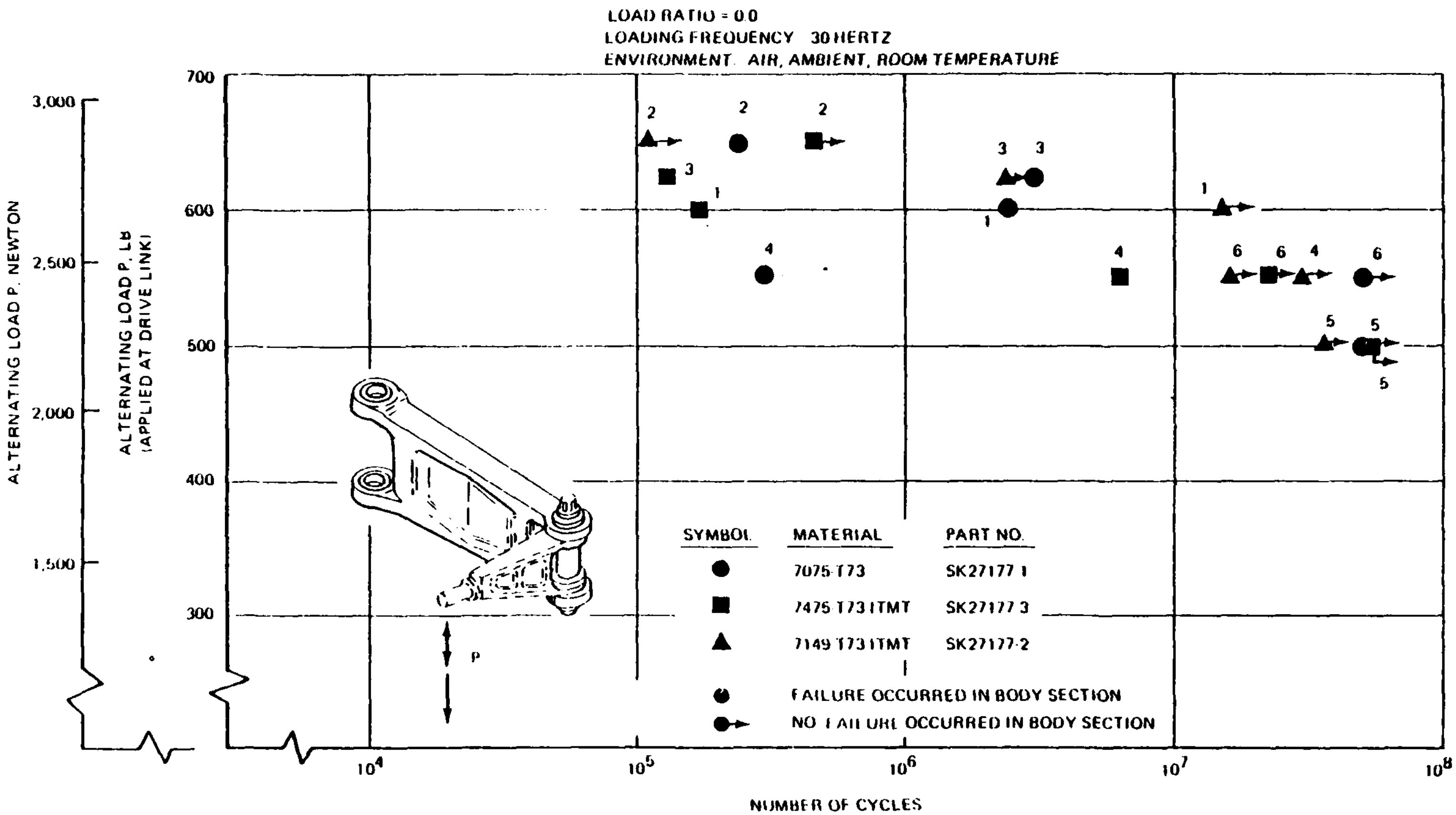


Figure 18. Plot of L-N Data for Drive Scissors Arm Assembly Body Section

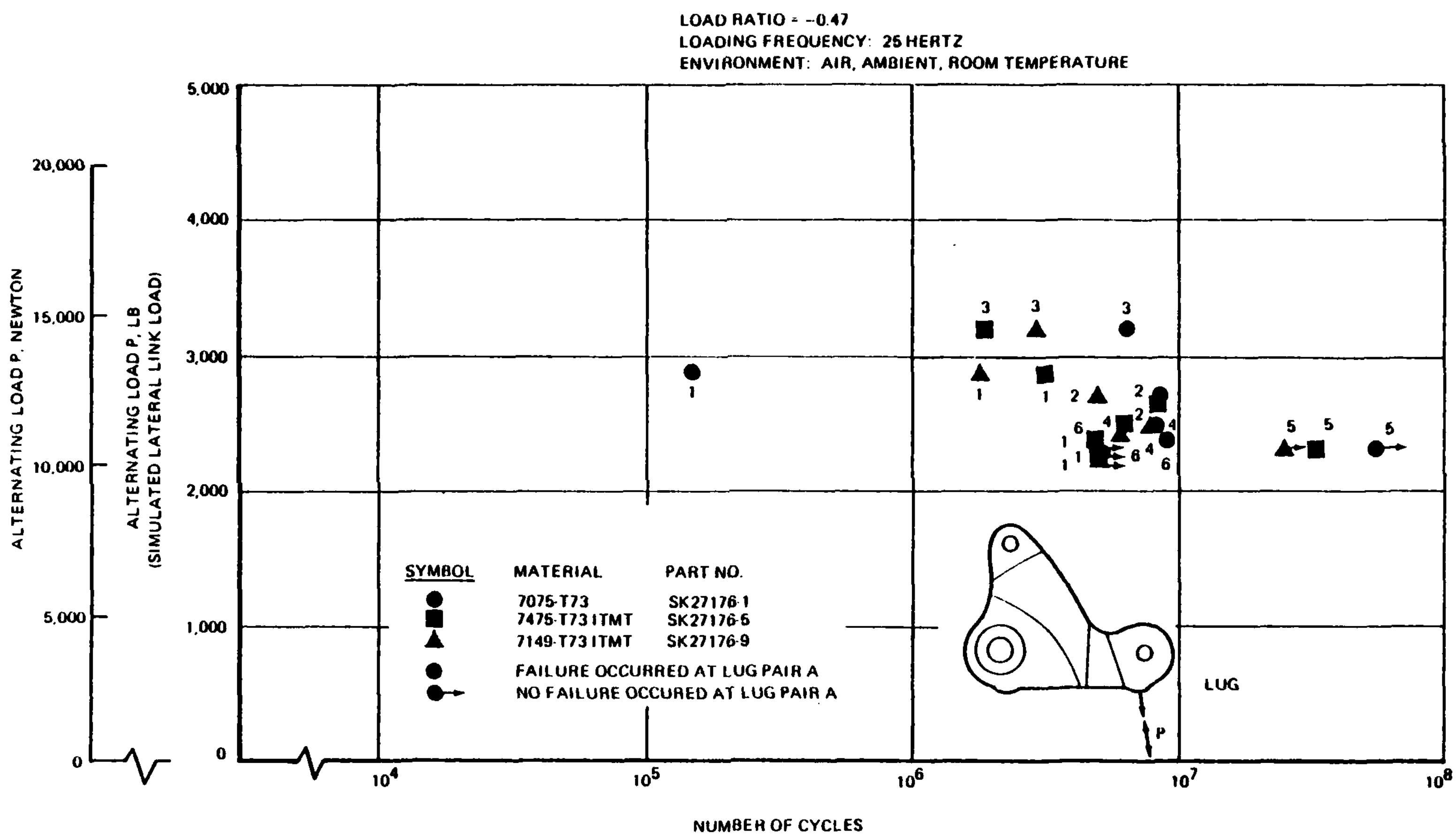


Figure 19. Plot of L-N Data for Lateral Differential Bellcrank Assembly, Lug Pair A Location

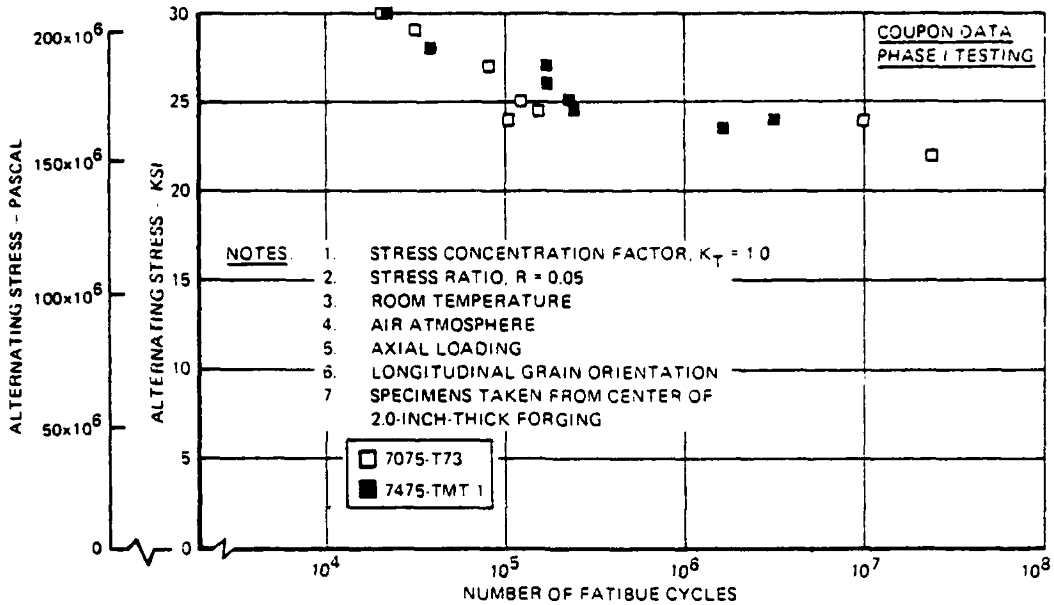


Figure 20. Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT1 Forgings, Groups 3 and 10 (From Reference 1).

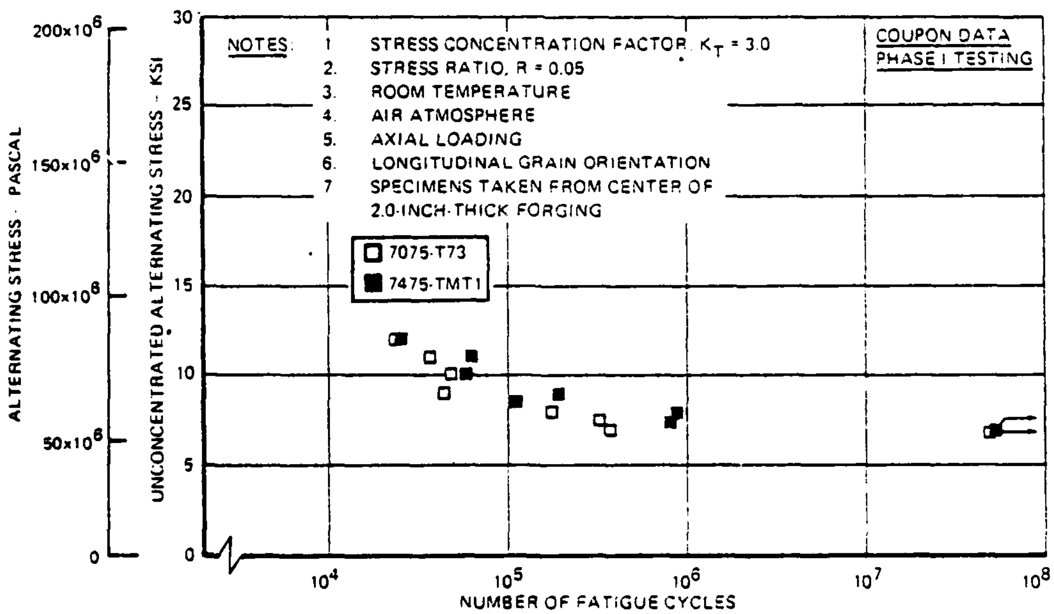


Figure 21 Comparison of Fatigue Strengths for 7075-T73 and 7475-TMT1 Forgings, Groups 4 and 13 (From Reference 1).

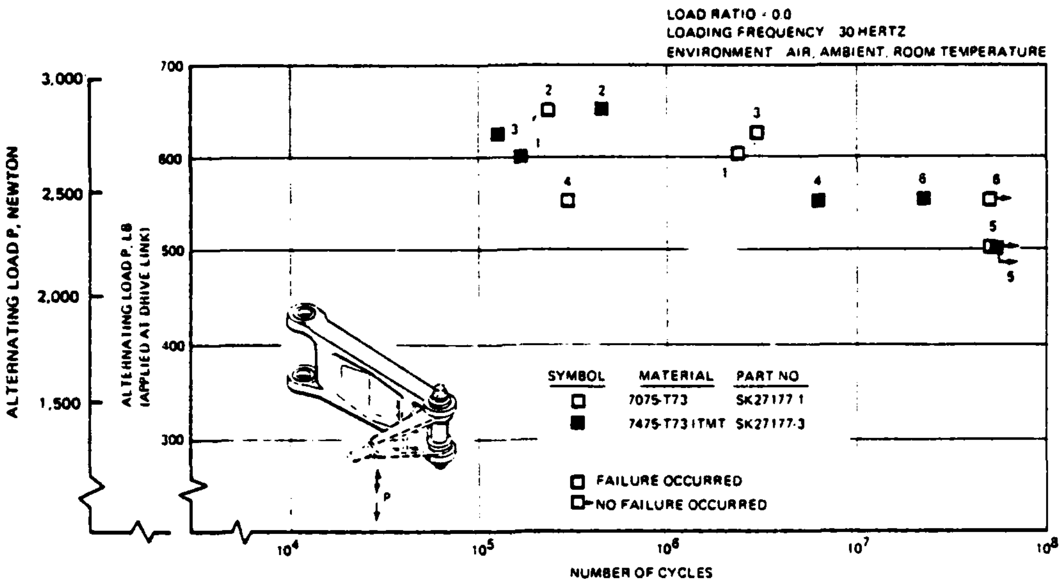


Figure 22. Plot of L-N Data for Drive Scissors Arm Assembly Specimens of 7075-T73 and 7475-T73 ITMT Materials

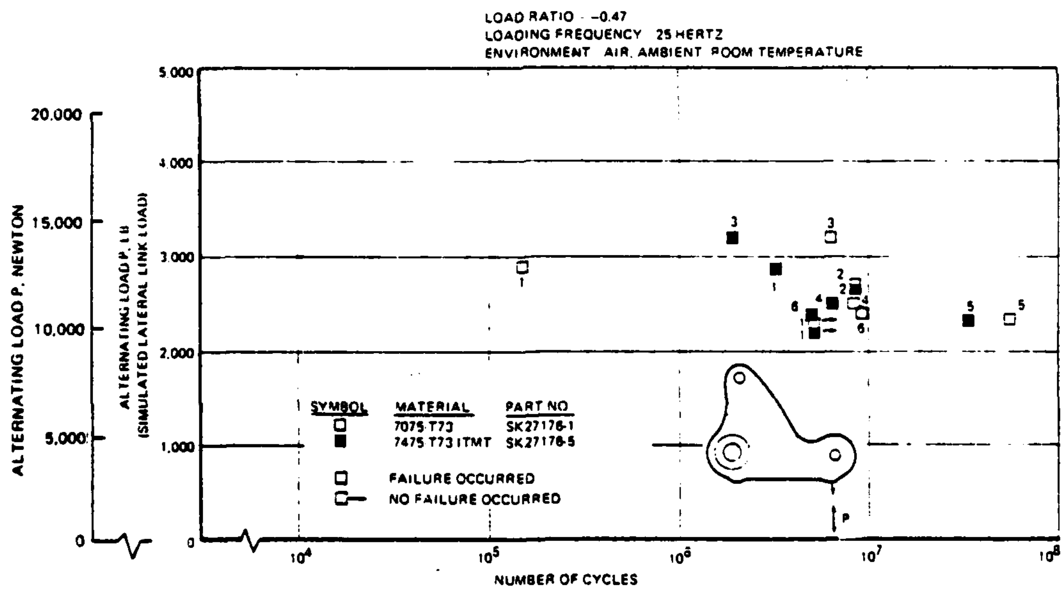


Figure 23. Plot of L-N Data for Lateral Differential Bellcrank Assembly Specimens of 7075-T73 and 7475-T73 ITMT Materials

strengths of the two alloy/processing combinations are similar in both coupon and components is considered significant. Referring to the results of Phase I coupon testing presented in Reference 1, it is noted that the significant fatigue strength improvements associated with the TMT processing occurred for thick sections (specimens from a 170mm (6.7-inch) thick forging) and a short transverse grain orientation. In general, the two helicopter components which were tested in this program were not critical with respect to those parameters (thicknesses as great as 152mm (6 inches) or critical stresses in the short transverse direction). Since, for similar conditions, the relative strengths determined from coupon tests and component tests were similar, it expected that the ITMT process applied to thick forgings with critical stresses in the short transverse direction would exhibit a higher fatigue strength than a conventionally processed forging of the same configuration.

Comparison With Components of Another Alloy

The fatigue strength performance of the helicopter dynamic system components tested in this program have been compared against previously tested components of the same configuration but of a different alloy.

Figure 24 presents a comparison of fatigue strength performance for the drive scissors arm assembly. The data points obtained in this program from the 7XXX-Series aluminum alloy specimens are shown. Also shown is the scatter band of data from previously tested drive scissors arm assembly specimens fabricated from 2014-T6 aluminum alloy forgings. The scatter band shown was based on tests of six specimens and was developed from the data contained in References 2 and 3. The comparison is presented to show data trends only and is not valid for making a rigorus direct comparison because of certain differences in design details. The specimens fabricated from the 2014-T6 material had certain features which acted as stress risers and were deleted from the specimens fabricated from the 7XXX-Series alloys. However, within the data scatter band of the 2014-T6 specimens, a number of different failure modes were exhibited, just as was the case with the 7XXX-Series alloy specimens. In some instances, the failure modes and local geometry of certain specimens within the two groups (2014-T6 and 7XXX-Series) are identical, thereby make possible a valid comparison for those limited number of specimens.

Figure 25 presents a comparison of fatigue strength performance for the lateral differential bellcrank assembly. The data points obtained in this program from the 7XXX-Series alloy specimens are shown. Also shown is the scatter band of data from previously tested bellcrank assembly specimens fabricated from 2014-T6 aluminum alloy forgings. The scatter band shown was based on tests of six specimens and was developed from the data contained in Reference 2. A direct valid comparison between the two groups of data can be made since specimen geometry was the same. The 7XXX-Series alloy specimens exhibit a higher average fatigue strength than the 2014-T6 specimens. In the case of the 7XXX-Series alloys specimens, the predominate failure location was lug pair "A" as identified in Table 5. In the case of the 2014-T6 specimens, the predominate failure location was lug pair "B".

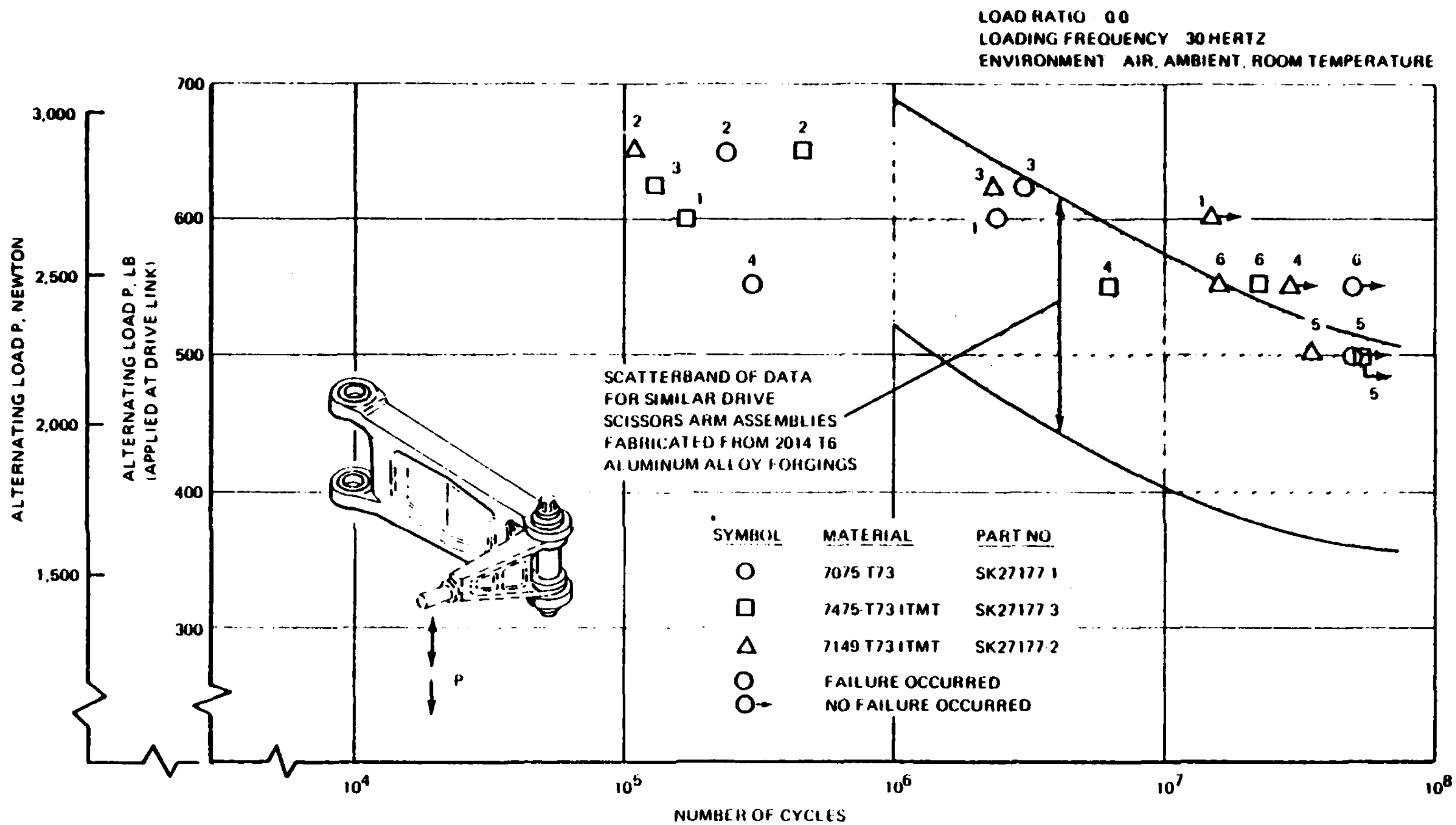


Figure 24. Comparison of Drive Scissors Arm Assembly Fatigue Test Data: 7XXX-Series Alloy Specimens Tested in Current Program Versus 2014 Alloy Specimens Tested in a Previous Program

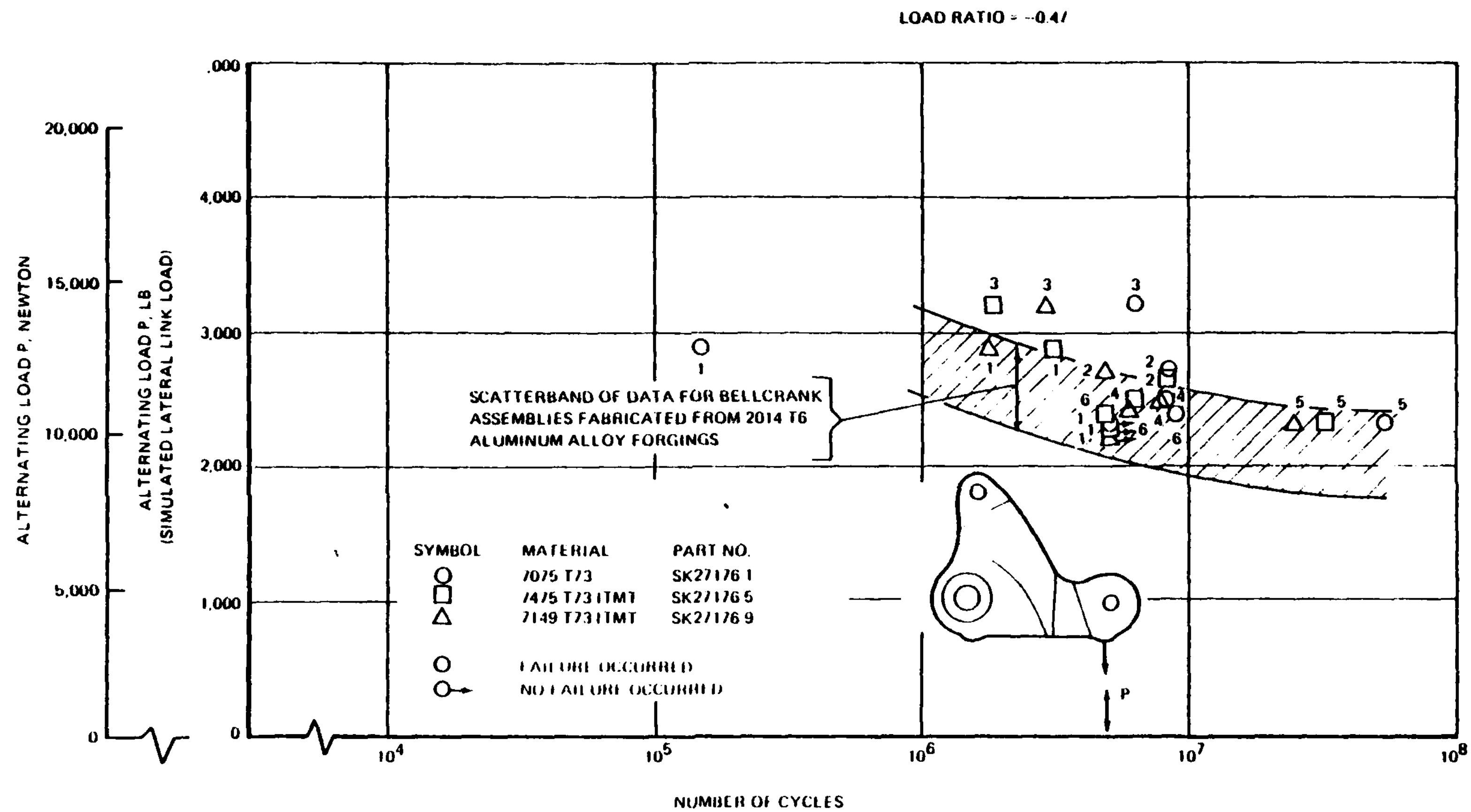


Figure 25. Comparison of Lateral Differential Bellcrank Assembly Fatigue Test Data: 7XXX-Series Alloy Specimens Tested in Current Program Versus 2014 Alloy Specimens Tested in a Previous Program

DAMAGE TOLERANCE DATA ANALYSIS

The fatigue crack propagation data presented in Table 6 illustrates a number of characteristics associated with the failure mode of bellcrank assembly test specimens. The pattern of cracking, while having some common characteristics, is not identical from specimen to specimen for the same nominal test conditions. The sequence in which the various cracks appear also differs from specimen to specimen. The data shown in Table 6 is for the lug pair A as identified in Table 5. As previously described, the fatigue cracking originates in an area of fretting at the bushing/lug interface. The cracks occur in one of the two lugs of the pair. The nature of the design is such that there is a slight offset of the lugs from the bellcrank body which results in one of the lugs offering a stiffer or more direct load path.

The fatigue cracks originate in the lug providing the more direct load path. As the cracking progresses, the relative percentage of the applied load which is carried by each of the two lugs changes. The lug with the growing crack(s) carries a decreasing percentage of the applied load. In the case of the three specimens shown in Table 6, all specimens were able to withstand the full value of the applied load even after extensive cracking had occurred in one of the two lugs of the pair.

In order to provide a straightforward indication of the relative damage tolerance of the three alloy/processing combinations, it was an initial objective to measure the fatigue crack propagation rates for the three combinations under conditions of identical loading and cracking mode. The fatigue cracking modes (such as presented in Table 6) exhibited by the components do not permit a direct comparison of fatigue crack growth rates to be made. Therefore, the most applicable measure of the damage tolerant characteristics of the three alloy/processing combinations is the fracture toughness and fatigue crack propagation data presented in Reference 1.

CONCLUSIONS

The objectives of this program were to achieve with intermediate thermal mechanical processing, die forgings of two aluminum alloys with tensile and stress corrosion resistance properties equivalent to conventional 7075-T73 die forging properties but with fatigue and fracture toughness properties twenty percent better than those of conventional 7075-T73 die forgings. Based on the tests and data analyses conducted in this program the following findings have been made:

1. The short transverse tensile and stress corrosion resistance properties of the 7475-T73 ITMT and 7149-T73 ITMT die forgings were found to be equivalent to or greater than those of the 7075-T73 die forgings (Table 3).

2. The fatigue strength of 7475-T73 ITMT and 7149-T73 ITMT die forgings were found to be approximately the same as those of the conventional 7075-T73 die forgings (Figures 16 and 17). It should be noted that the Phase I program coupon testing described in Reference 1 would have predicted essentially the same fatigue performance for the ITMT and conventionally processed forgings in the size range of the components which were tested. The significant increase in fatigue strength related to the ITMT processing per Reference 1 was seen with thick sections and loading in the short transverse grain direction. The components tested in this program did not possess these characteristics; however, the correlation with coupon data which was seen indicates that it is reasonable to expect ITMT processed die forging to exhibit improved fatigue strength for thick forgings with critical stresses in the short transverse grain direction.

3. The fatigue strength exhibited by the 7XXX-Series aluminum alloy forgings tested in this program was equivalent to or greater than that of the 2014-T6 forgings presently utilized for production components.

RECOMMENDATIONS

The results of this test program indicate that the potential benefits from intermediate thermal mechanical treatment may be very dependent on component configuration. In order to establish the guidelines for determining the instances where the ITMT approach may be cost effective, a two phase approach is recommended. In the initial phase, an in-depth metallurgical and failure modes investigation would be conducted on the coupons and components tested to date in both the program described in Reference 1 and the program described herein. The objective of this program would be the correlation of mechanical properties with metallurgical characteristics. Contingent on the findings of that program, it is recommended that an aircraft component, selected for potential properties improvement by the ITMT process, be fabricated for side-by-side test evaluation with a conventionally forged aluminum component. At the present time, it would appear that the candidate component would involve thick sections with critical stresses in the short transverse grain direction.

REFERENCES

1. Zola, J. C., Improvement of Helicopter Skin Material by Controlled Solidification and Thermal-Mechanical Treatments, Final Report, U.S. Army Frankford Arsenal Contract DAAA25-74-C-0448, March 1976.

2. Boeing Vertol Report 107M-S-20, Fatigue Strength Substantiation, Dynamic System, CH-46D Helicopter, June 1970.

3. Boeing Vertol Report 107M-T-150, Final Report, Bench Fatigue Tests of Control System Components and Assemblies for Boeing Vertol CH-46A Helicopter, October 1969.

BIBLIOGRAPHY

Cebulak, W. S., and Truax, D. J., PROGRAM TO DEVELOP HIGH STRENGTH ALUMINUM POWDER METALLURGY PRODUCT, PHASE III - SCALE UP A, Final Report, U.S. Army Frankford Arsenal Contract DAAA25-70-C-0358, September 1972.

Sommer, A. W., Paton, N.E., and Folgner, D. G., EFFECTS OF THERMOMECHANICAL TREATMENTS ON ALUMINUM ALLOYS, AFML-TR-72-5, February 1972.

Thompson, D.S., Levy, S. A., Spangler, G. E., and Benson, D. K., PROGRAM TO IMPROVE THE FRACTURE TOUGHNESS AND FATIGUE RESISTANCE OF ALUMINUM SHEET AND PLATE FOR AIRCRAFT APPLICATIONS, WPAFB Contract F33615-72-C-1202, Semiannual report for the period June 1, 1972, to December 31, 1972, January 1973.

Conserva, M., DiRusso, E., and Gatto, F., A NEW THERMOMECHANICAL TREATMENT FOR Al-Zn-Mg TYPE ALLOYS, Alumino e Nuovo Metallurgia, 9, 441-445, 1968.

Ostermann, F., IMPROVED FATIGUE RESISTANCE OF Al-Zn-Mg-Cu (7075) ALLOYS THROUGH THERMOMECHANICAL PROCESSING, Metallurgical Transactions, 2, 2897-2902, 1971.

Ruch, L., and Sulinski, H., FINAL THERMAL MECHANICAL TREATMENT OF 7039, 7075, X7007, AND X7050 ALLOYS, Frankford Arsenal Report (in preparation).

Hyatt, M. V., Early, D.O., and Pasley, D. H., PROGRAM TO IMPROVE THE FRACTURE TOUGHNESS AND FATIGUE RESISTANCE OF ALUMINUM SHEET AND PLATE FOR AIRFRAME APPLICATIONS, WPAFB Contract No. F33615-72-C-1649, Semiannual report for period July 1, 1972, to December 31, 1972, January 1973.

Waldman, J.,Sulinski, H., and Marksu, H., NEW PROCESSING TECHNIQUES FOR ALUMINUM ALLOYS, presented at the Army Materials Technology Conference on Solidification Technology, Wentworth by the Sea, New Hampshire, October 1972.

Boyd, J. D., Drennan, D. C., Martin, C. J., Price, C. W., Rosenfield, A. R., and Williams, D. N., RESEARCH ON SYNTHESIS OF HIGH STRENGTH ALUMINUM ALLOYS, Technical Report AFML-TR-72-199, July 1, 1971 to July 31, 1972.

1964 BOOK OF ASTM STANDARDS, PART 30, GENERAL TESTING METHODS; QUALITY CONTROL; APPEARANCE TESTS; TEMPERATURE MEASUREMENT; EFFECT OF TEMPERATURE, American Society for Testing and Materials, Philadelphia, Pennsylvania.

STANDARD TENSION TEST, E8-61T, American Society for Testing and Materials, Philadelphia, Pennsylvania.

TENTATIVE METHOD OF TEST FOR PLANE-STRAIN FRACTURE TOUGHNESS OF METALLIC MATERIALS, E399-72T, American Society for Testing and Materials, Philadelphia, Pennsylvania.

Grover, H. J., Gordon, S. A., and Jackson, L. R., FATIGUE OF METALS AND STRUCTURES, DEPARTMENT OF THE NAVY, June 1960.

Fenner, A. J., Wright, K. H. R., and Mann, J. Y., FRETTING CORROSION AND ITS INFLUENCE ON FATIGUE FAILURES, International Conference on Fatigue of Metals, London, Institution of Mechanical Engineers, 1956.

Heywood, R. B., DESIGNING AGAINST FATIGUE, Chapman and Hall, 1962.

APPENDIX A

COMPONENT DRAWINGS

Figures A1, A2, A3, and A4 present the detailed dimensional information pertinent to the test components evaluated in this program. Figures A1 and A3 show the modifications made to the standard production version of the drive scissors arm assembly and the lateral differential bellcrank assembly respectively. The basic production configurations of these components are shown in Figures A2 and A4.

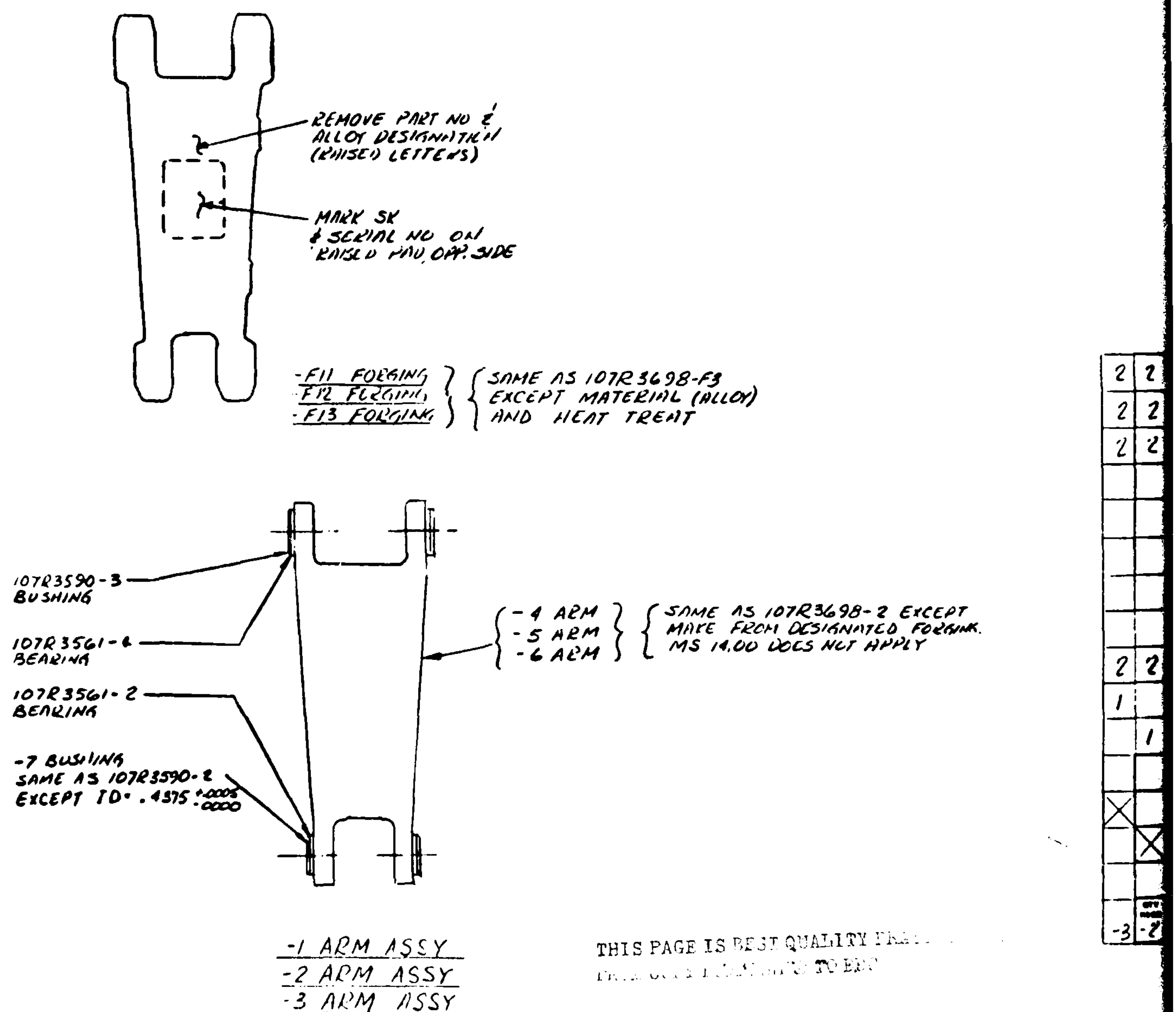


Figure A1. Drawing SK27177, Arm Assembly, Improved Helicopter Component Forgings

NOTES

2 HEAT TREAT TO -T73 PER MIL-H-6088

3 7049-ITMT ALUMINUM ALLOY

4 7475-ITMT ALUMINUM ALLOY

5 SPECIAL HEAT TREATMENT BY MATERIAL SUPPLIER.

2	2	2		107R3590-3	BUSHING							
2	2	2		107R3561-4	BEARING							
2	2	2		107R3561-2	BEARING							
				-F13	FORGING	4	5					
				-F12	FORGING	3	2					
				-F11	FORGING	7075 ALUM. ALLOY PER QQ-A-367	2					
2	2	2		-7	BUSHING	SEE DWG 107R3590						
1				-6	ARM	MAKE FROM -F13 FORGING		VF-3.0				
	1			-5	ARM	MAKE FROM -F12 FORGING		VF-3.0				
		1		-4	ARM	MAKE FROM -F11 FORGING		VF-3.0				
X				-3	ARM ASSEMBLY							
	X			-2	ARM ASSEMBLY							
		X		-1	ARM ASSEMBLY							
-3	QTY REQD -2	QTY REQD -1	CODE IDENT NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	MATERIAL AND SPECIFICATION		FINISH		CALC UNIT WT	ACT UNIT WT	REV LTR

PARTS LIST

DIMENSIONING & TOLERANCING PER ANSI (USASI) Y14.5

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

TOLERANCES: ANGLES ±

DECIMALS .XX ±

DECIMALS .XXX ±

RIVET & BOLT EDGE MARG ±

BEND RADII

SHEET METAL CORNER RADII

DATA REVIEW		
DWG QUAL		
STRUCT	R.L.	1-10-77
MATL & PROC	L. CLUBST	1-10-77
WTS		
CHANGE/ITEM NUMBER		

CONTRACT NUMBER	
DAAM25-77 C0015	
DRN FE MAMROL	1-10-77
CHK	
ENGR	
DRG	
PROJECT APPROVAL	

BOEING VERTOL COMPANY

PHILADELPHIA PENNSYLVANIA 19142

ARM ASSEMBLY IMPROVED HELICOPTER COMPONENT FORGINGS

SIZE	CODE IDENT NO	
D	77272	SK 27177

SCALE —

FASTENER CODES

DWG DRNG BY ORDER 7540

SK 27177 REV

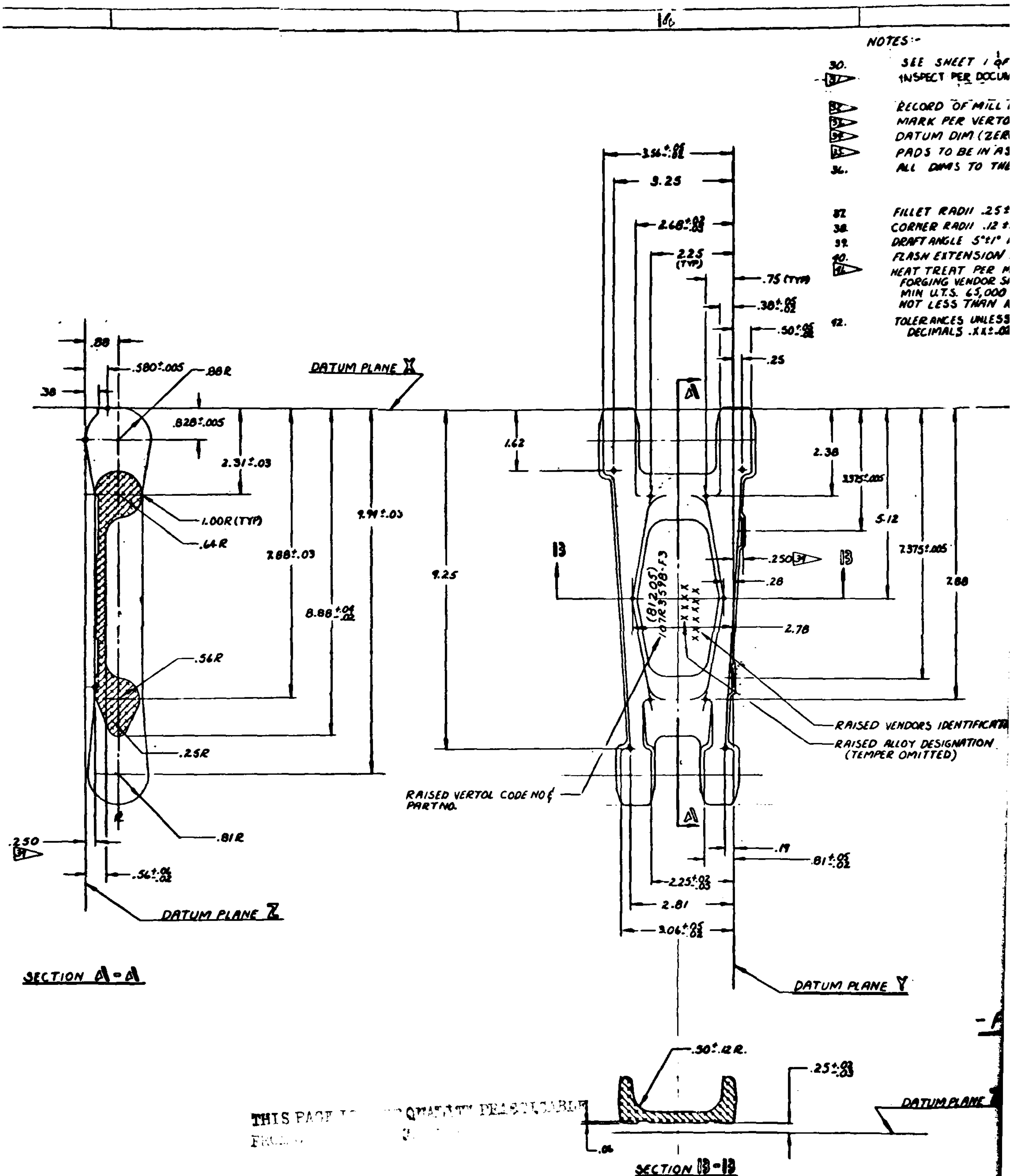
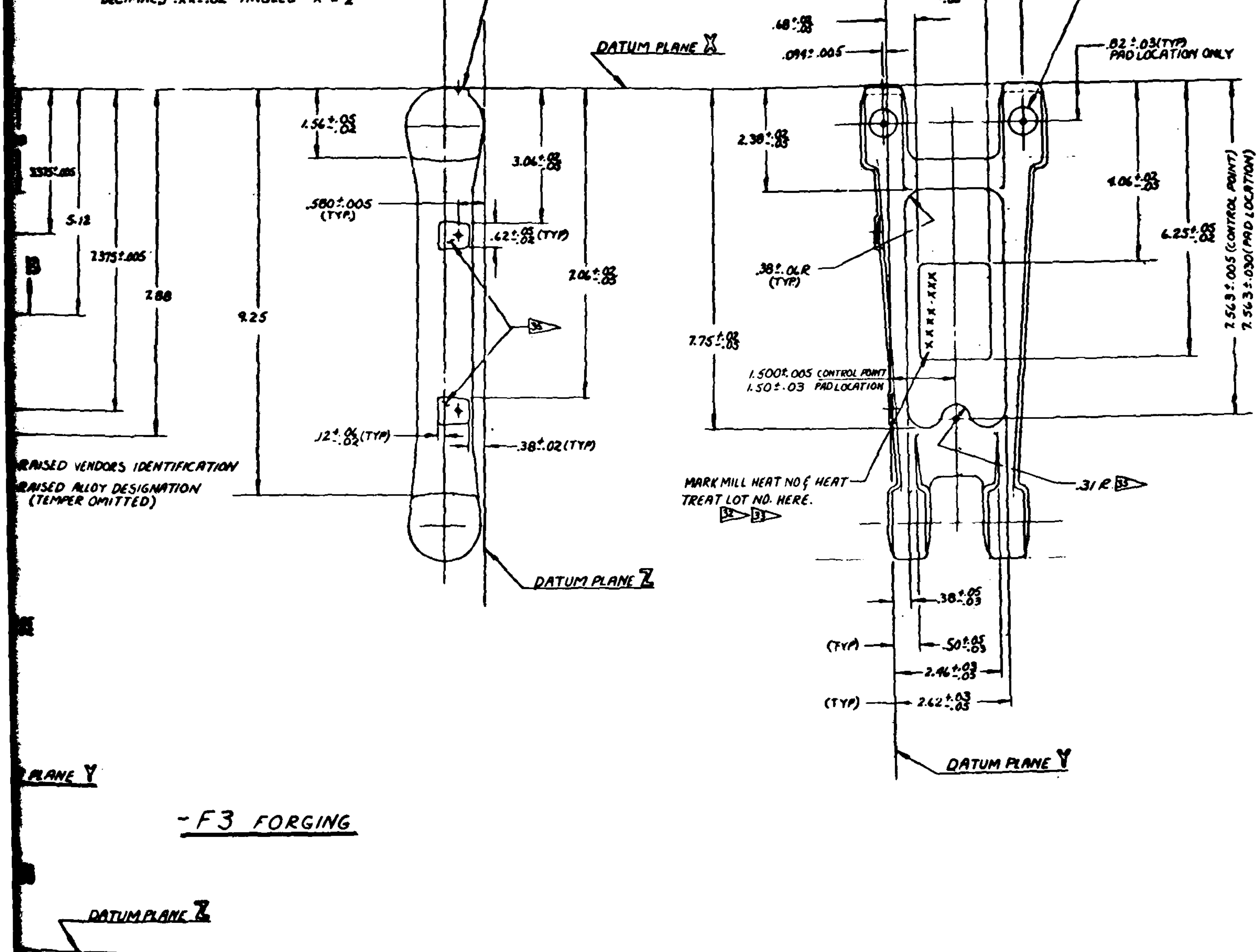


Figure A2. Drawing 107R3598, Drive Scissors Arm Assembly, Upper Rotor Controls (Sheet 1 of 3)

12 | 11

NOTES:-

- SEE SHEET 1 OF 2 FOR MACHINED PART.
- INSPECT PER DOCUMENT D-10875.
- RECORD OF MILL HEAT & HEAT TREATMENT SHALL BE FURNISHED VERTOL.
- MARK PER VERTOL SPEC. MS13.01 GROUP I
- DATUM DIM (ZERO TOL) FOR LOCATION OF DATUM PLANE.
- PADS TO BE IN AS FORGED CONDITION, NO GRINDING PERMITTED.
- ALL DIMS TO THEORETICAL SHARP CORNERS UNLESS OTHERWISE NOTED.
- FILLET RADII .25±.04 UNLESS OTHERWISE NOTED.
- CORNER RADII .12±.03 UNLESS OTHERWISE NOTED.
- DRAFT ANGLE 5°±1° AND MATCHED WHERE NECESSARY, UNLESS OTHERWISE NOTED.
- FLASH EXTENSION .06 MAX.
- HEAT TREAT PER MIL-H-6088 & VERTOL SPEC. 12-9
  FORGING VENDOR SHALL SUPPLY FORGING IN T6 CONDITION.
  MIN U.T.S. 65,000 PSI FORGING TO BE QUENCHED IN HOT WATER
  NOT LESS THAN 160°F.
- TOLERANCES UNLESS OTHERWISE NOTED
  DECIMALS .XX±.02 ANGLES X°±1°



-F3 FORGING

DATUM PLANE Z

THIS DRAWING NOT COMPLETE WITHOUT APPLICABLE INFORMATION SHOWN ON SHEET 1

ARM ASSEMBLY, DRIVE SCISSORS—UPPER ROTOR CONTROLS

VERTOL

J 107R3598

SCALE FULL | CODE IDENT NO. 77272 | SHEET 2 OF 2

CODE IDENT NO. 77272 SH 2
DWG NO 107R3598

13 | 12 | 11

1 | 2

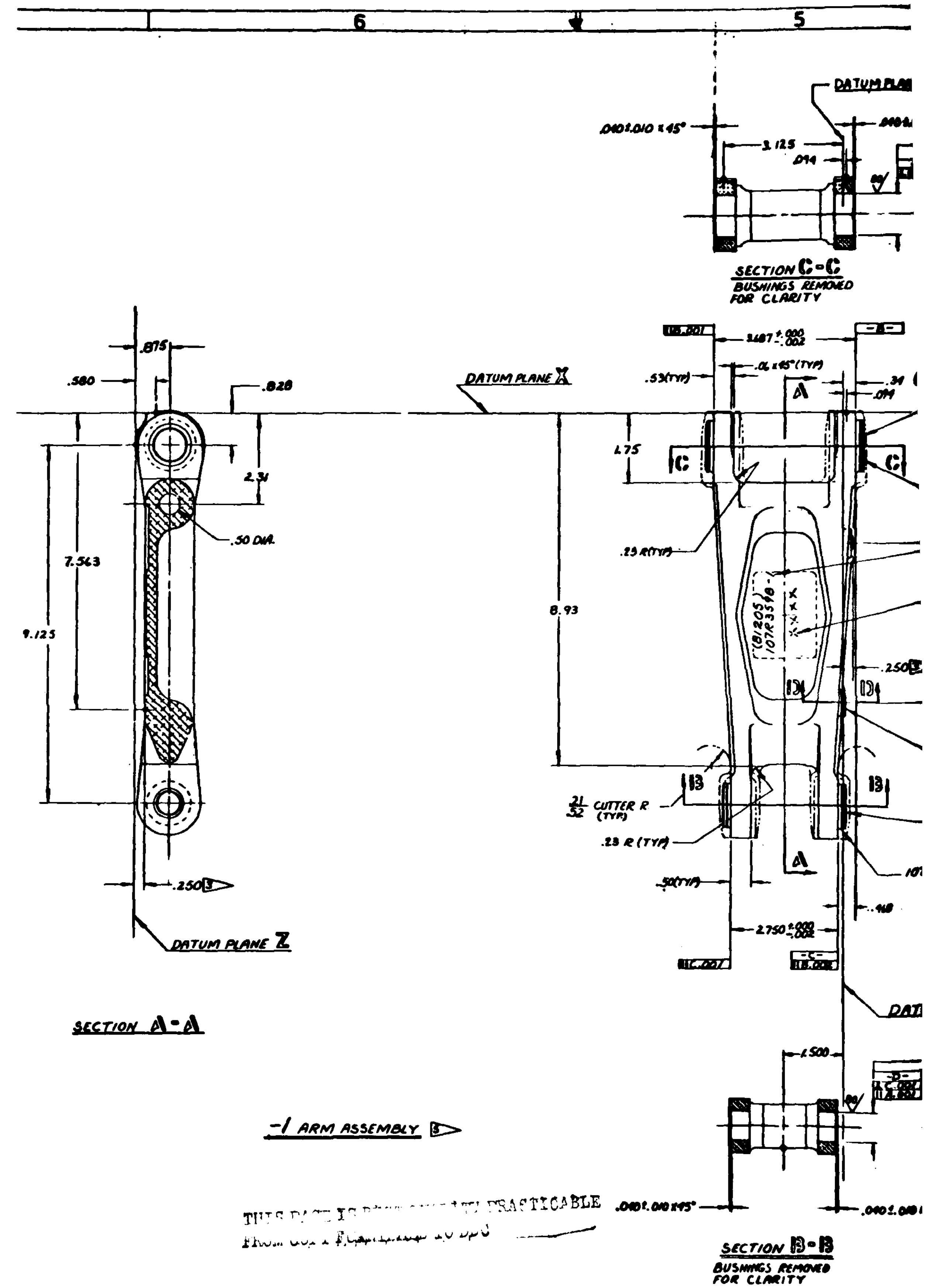
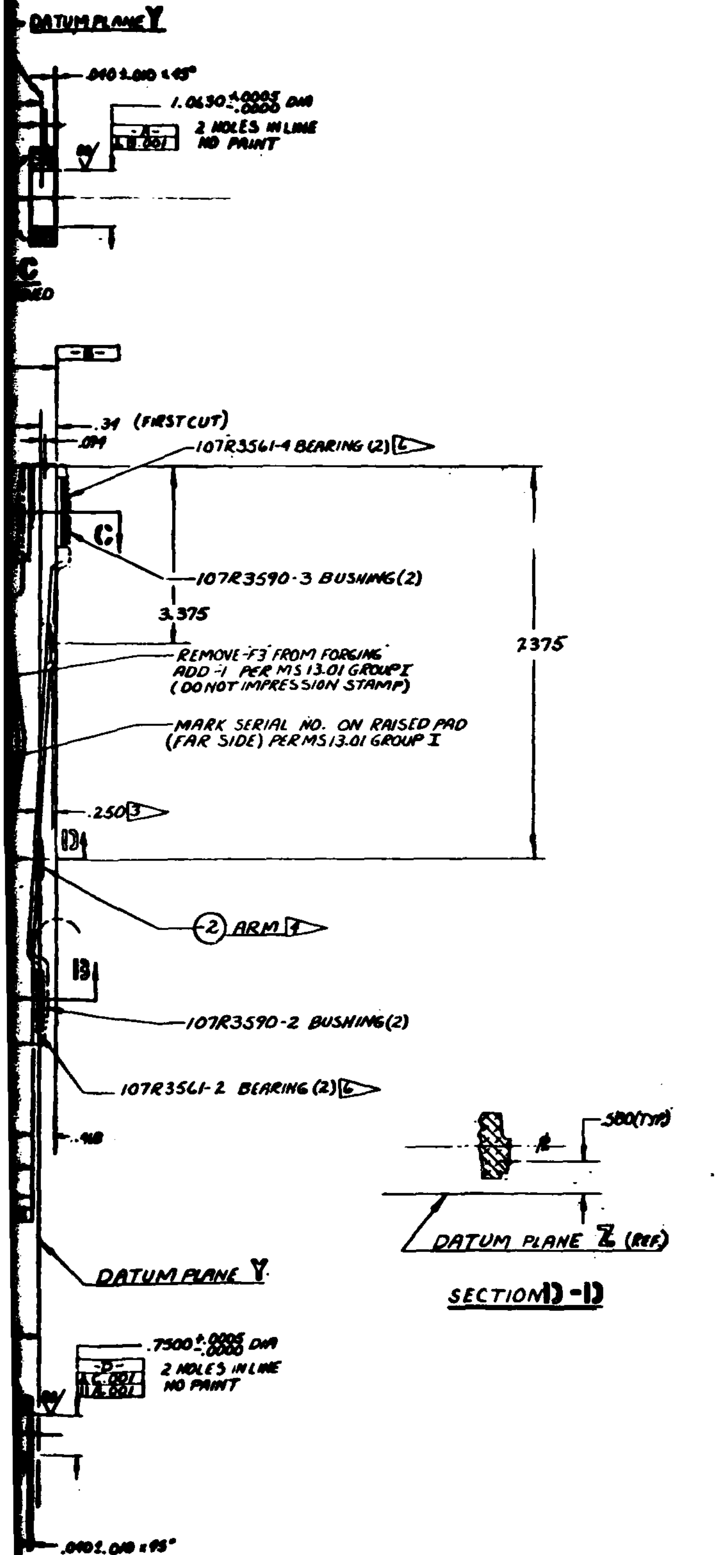


Figure A2. Drawing 107R3598, Drive Scissors Arm Assembly, Upper Rotor Controls (Sheet 2 of 3)



SECTION D-D

PROPRIETARY NOTE

NO. 62-01714

NOTES:-

1. MANUFACTURING STANDARDS PER VERTOL STANDARD VS 60904, UNLESS OTHERWISE NOTED.
2. 125/ MAX MACHINED SURFACE FINISH PER MIL-STD-10 UNLESS OTHERWISE NOTED.
3. DATUM DIM. (ZERO TOL.) FOR LOCATION OF DATUM PLANE.
4. THIS PART REQUIRES CLASS "B" QUALITY CONTROL PER VERTOL BULLETIN IP-1 (FOR VERTOL AND/OR VENDOR QUALITY CONTROL ONLY)
5. THIS PART REQUIRES CLASS "D" QUALITY CONTROL PER VERTOL BULLETIN IP-1 (FOR VERTOL AND/OR VENDOR QUALITY CONTROL ONLY)
6. SEAL BETWEEN BEARING & ARM USING MIL-S-22473 GRADE 30. SEALING COMPOUND APPLIED PER THE FOLLOWING INSTRUCTIONS:-
   a) SURFACES OF PARTS SHOULD BE SOLVENT DEGREASED PRIOR TO INSTALLING
   b) APPLY ACTIVATOR TO O.D. OF BEARING AND ALLOW TO DRY, PRIOR TO COOLING PER MS2L06
   c) INSTALL BEARINGS IN THEIR RESPECTIVE BORES AND ALLOW ASSY TO REACH ROOM TEMP.
   d) APPLY A FILLET OF SEALANT ALONG PARTING LINES:- REPEAT AS NECESSARY TO MAINTAIN A FILLET. CAUTION: NO SEALANT PERMITTED ON TEFLON SURFACES.
   e) ALLOY TO DRY FOR 12 HOURS AT ROOM TEMPERATURE OR HEAT ASSEMBLY TO 180°±10°F IN AN AIR OVEN FOR THIRTY (30) MINUTES
   f) WIPE OFF EXPOSED SEALANT WHICH DID NOT DRY WITH A CLEAN CLOTH MOISTENED WITH NAPTHA OR EQUIVALENT SOLVENT.
7. MATERIAL SUBSTITUTION AND EQUIVALENTS PER 08-0127.
8. VENDOR ITEM - SEE SPECIFICATION CONTROL OR SOURCE CONTROL DRAWING.

CH-46F	N2	107R3507
107-II-25	N1	107R3507
CH-46A	N1	107R3507
107-II	N1	107R3507
MODEL	PART NO. CODE	NEXT ASSEMBLY

CODE IDENT NO. 77272 | SH 1
DWG. NO. 107R3598

4 3

2

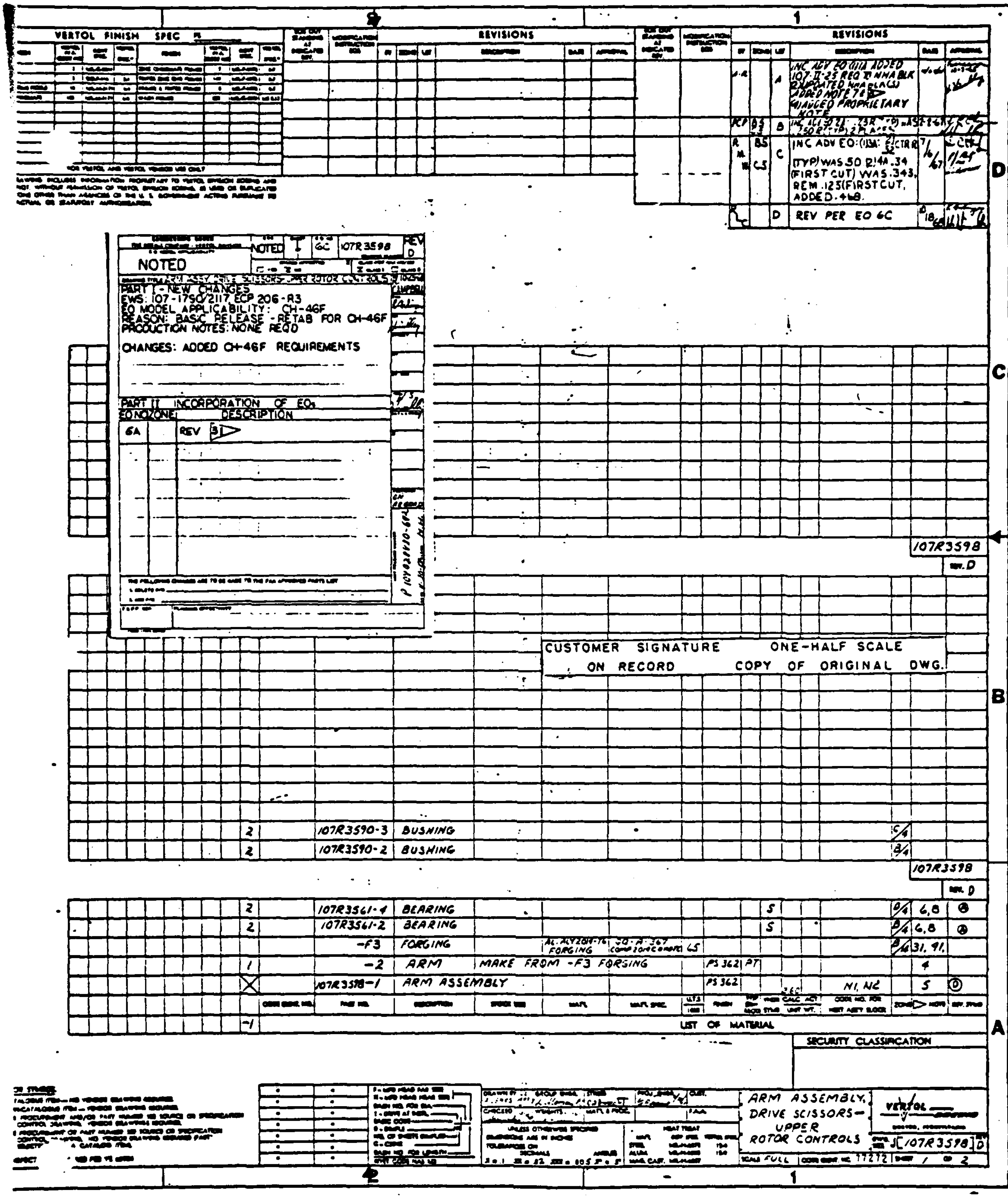


Figure A2. Drawing 107R3598, Drive Scissors Arm Assembly, Upper Rotor Controls (Sheet 3 of 3)

GENERAL NOTES

1. STRIKE FORGING FROM 107C2652 -F13 DIE.
2. MACHINING OF THIS PART TO BE IN ACCORDANCE WITH THAT OF -12 FROM 107C2652.
3. THIS ASSY. IS TO USE THE IDENTICAL HARDWARE AS CALLED FOR IN A -11 ASSY. FROM DWG 107C6252.
4. HEAT TREAT RAW FORGING TO TEMPER T73 PER MIL-H-6088.
5. HEAT TREAT RAW FORGING TO TEMPER T73 PER ALCOA SPEC.
6. ALL FABRICATION PROCESSES, FINISHES AND STANDARDS TO BE PER DWG 107C2652 (-11, -12 & -F13). BOTH GENERAL NOTE COLUMNS TO BE APPLICABLE EXCEPT THE FOLLOWING:

   15, 16, 17, 18, 19 & 62

Figure A3. Drawing SK27176, Lateral Differential Bellcrank Experimental Components

THIS DWG RELEASED BY TLR* HMC (1.1.7-01

THIS DRAWING IS NOT COMPLETE WITHOUT DWG 107C2652

-9	-5	-1	Code Ident	Part or Identifying No.	Nomenclature	Material			Finish					
				SK-27176-F11	FORGING	AL ALLOY 7049 ITMT	1	4	PS-362					
1				SK-27176-10	BELLCRANK MAKE	FROM -F11 FORGING	2		PS-362	VE				
/				SK-27176-9	BELLCRANK ASSY.		3		PS-362					
				SK-27176-F7	FORGING	AL ALLOY 7475 ITMT	1	5	PS-362					
	1			SK-27176-6	BELLCRANK MAKE	FROM -F7 FORGING	2		PS-362	VE				
	/			SK-27176-5	BELLCRANK ASSY.		3		PS-362					
				SK-27176-F3	FORGING	AL ALLOY 7075-T73	1	4	PS-362					
		1		SK-27176-2	BELLCRANK MAKE	FROM -F3 FORGING	2		PS-362	VE				
		/		SK-27176-1	BELLCRANK ASSY.		3		PS-362					

PARTS LIST

J. DETWILER 4/6/77

BOEING VERTOL COMPANY

PHILADELPHIA PENNSYLVANIA 19142

BELLCRANK -
LATERAL DIFFERENTAL,
EXPERIMENTAL COMPONENTS

D 77272 SK-27176

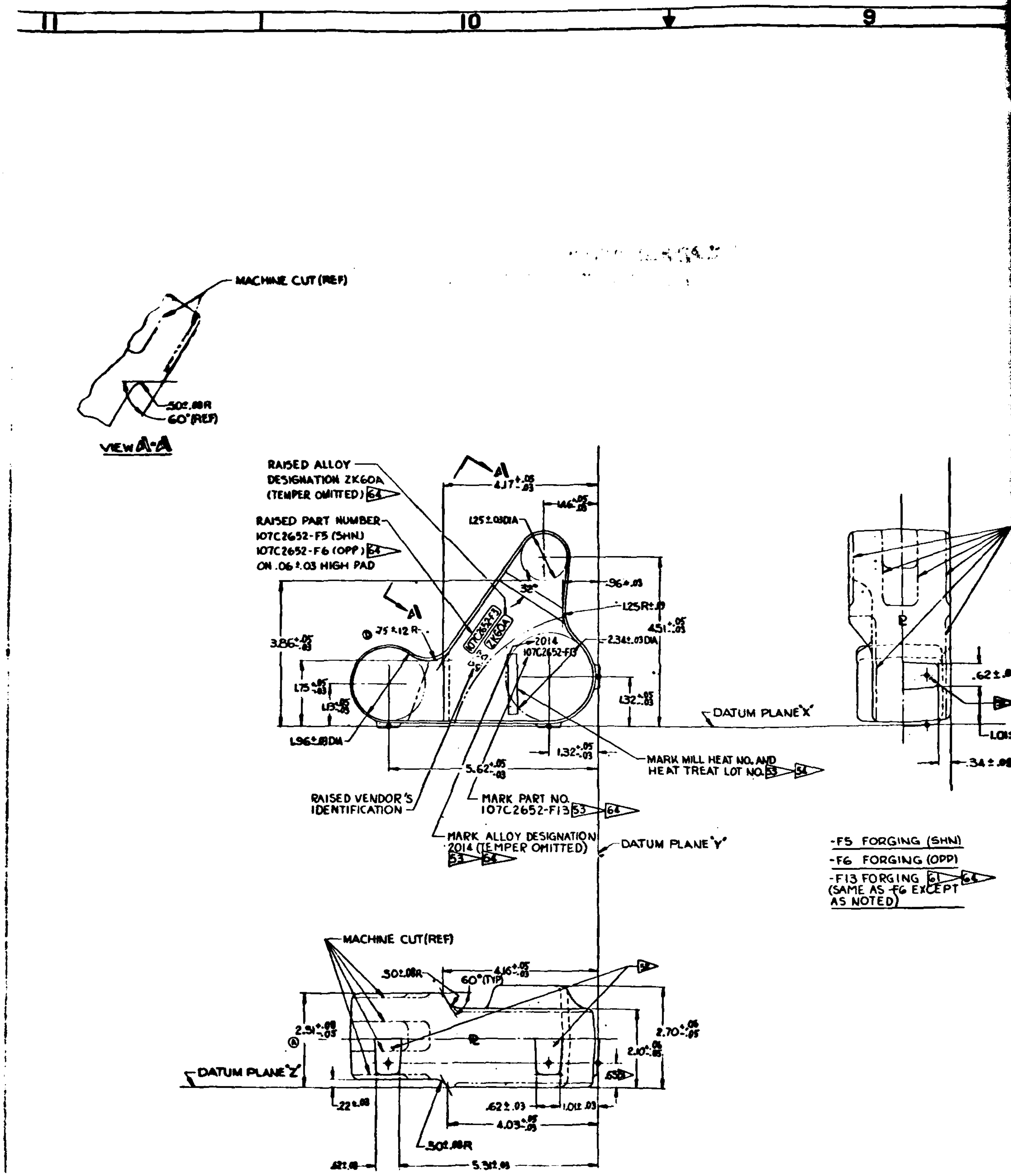


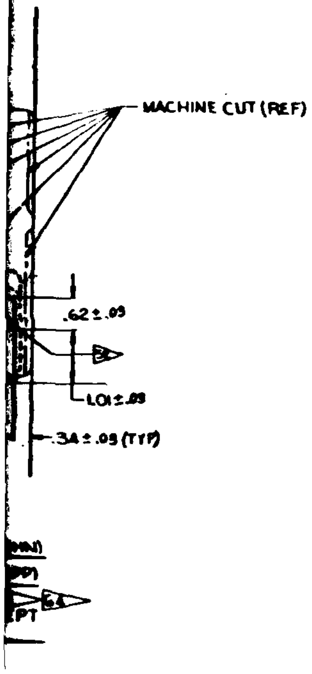
Figure A4. Drawing 107C2652, Lateral Differential Bellcrank Assembly (Sheet 1 of 3)

8

NOTES: RAW FORGING

51. DATUM DIMENSION (ZERO TOLERANCE) FOR LOCATION OF DATUM PLANES.
52. PADS SHALL BE AS FORGED-NO GRINDING PERMITTED.
53. MARK IN ACCORDANCE WITH VERTOL SPEC. MS 13.01 GROUP I.
54. RECORDS OF MELT & HEAT TREATMENT SHALL BE FURNISHED VERTOL AIRCRAFT CORP.
55. ALL CORNER RADII TO BE .19±.03 EXCEPT AS NOTED.
56. DRAFT ANGLE 5°±1° MATCHED WHERE NECESSARY
57. MAXIMUM FLASH EXTENSION TO BE .03
58. CORNER RADII ON PADS TO BE .12±.03R. FILLET RADII AT PADS TO BE .12±.03R
59. SPECIFIED TOLERANCES INCLUDE DIE CLOSURE, LINEAR, STRAIGHTNESS AND MISMATCH TOLERANCES AS APPLICABLE

60. INSPECT RAW FORGING PER VERTOL SPEC MS 14.08 FOLLOWED BY FLUORESCENT PENETRANT INSPECTION PER SPEC. MIL-I-6866
61. 107C2652-F13 FORGING IS TO BE STRUCK FROM THE 107C2652-F6 DIE.
62. HEAT TREAT RAW FORGING TO TEMPER T6 (62,000 PSI UTS MIN) PER MIL-H-6088. FORGING SHALL BE QUENCHED IN HOT WATER NOT LESS THAN 160°F.
63. FOR-F13 ONLY. INSPECT PER DOCUMENT D-10875
64. FOR -F13 ONLY. REMOVE THE EXISTING RAISED PART NO. 107C2652-F6 AND RAISE ALLOY DESIGNATION ZK60A. GRINDING IS PERMISSIBLE BUT NOT TO EXTEND BELOW THE PARENT FORGED SURFACE. FOR REIDENTIFICATION SEE FIELD OF DRAWING.

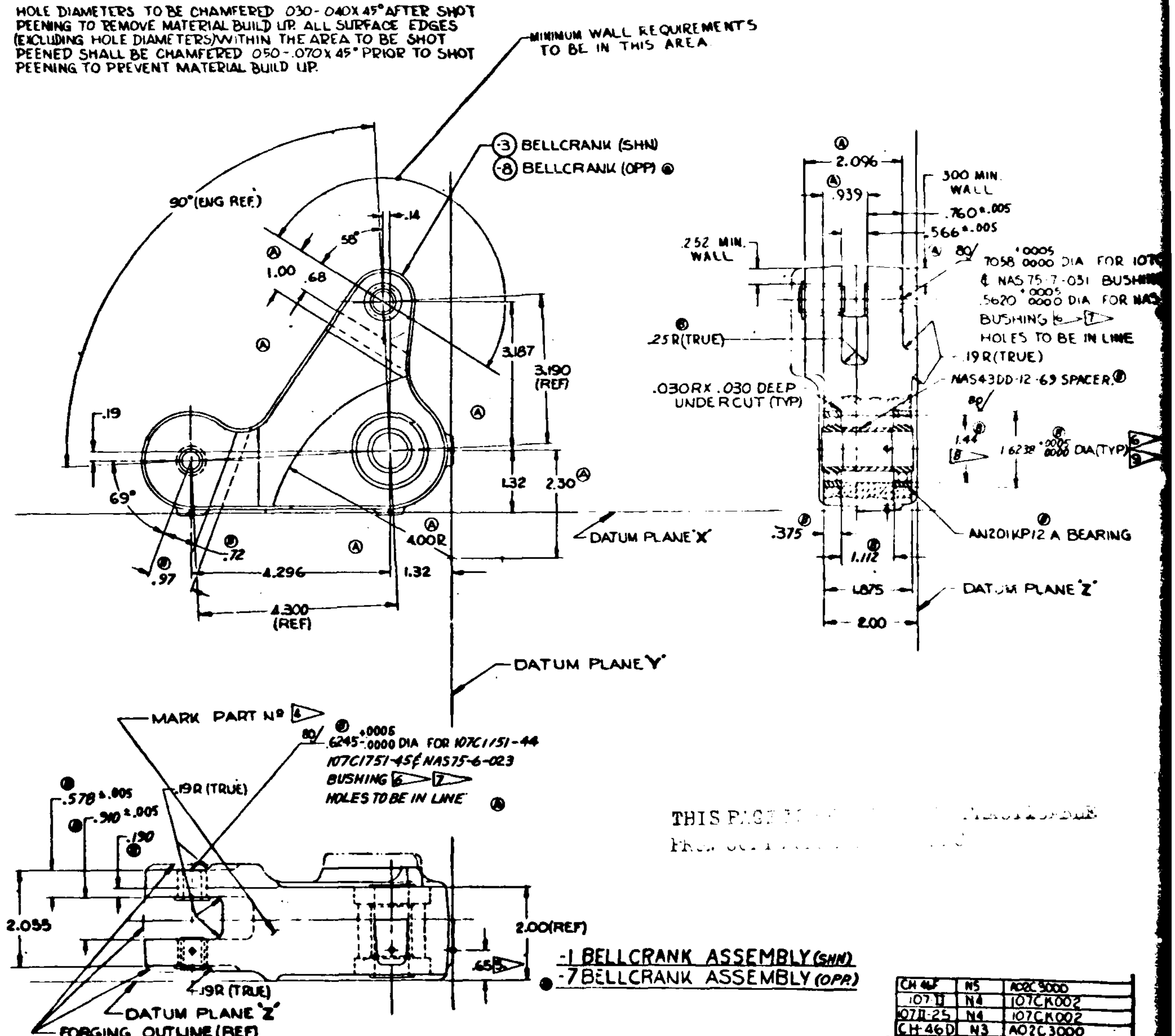


CODE IDENT 77272	SHEET	
DRAWING NO 107C2652	1 of 2	

8

NOTES: MACHINED FORGING

1. MANUFACTURING STANDARDS PER VERTOL STANDARD VS 60904 UNLESS OTHERWISE NOTED
2. TOLERANCE ON MACHINED DIMENSIONS .XX±.02, .XXX±.010, X°±½°
3. 125/ MAXIMUM MACHINE SURFACE FINISH PER MIL-STD-10 UNLESS OTHERWISE NOTED.
4. MARK IN ACCORDANCE WITH VERTOL SPEC. MS 13 GROUP III A
5. DATUM DIMENSION (ZERO TOLERANCE) FOR LOCATION OF DATUM PLANE.
6. MASK THESE DIAMETERS FROM PAINT.
7. PROVIDE DISSIMILAR METAL CONTACT PROTECTION PER PS 562
8. DIAMETER TO BE CONCENTRIC WITH BEARING BORES WITHIN .020 T.I.R. (ONE SIDE ONLY)
9. BEARING BORES TO BE CONCENTRIC WITHIN .008 T.I.R
10. PARTIAL CLEAN-UP OF FORGED SURFACE BY MACHINE CUT IS ACCEPTABLE PROVIDING .324 MINIMUM WALL REQUIREMENT IS MET.
11. SHOT PEEN ENCLOSED AREA INCLUDING INSIDE OF .562 DIA AND .7058 DIA HOLES PER MS 21.01
    SHOT SIZE: S460 STEEL SHOT
    ARC HEIGHT: .012 TO .014 ALMEN A2
    COVERAGE: 200%
    HOLES MAY BE HONED OR BURNISHED AFTER SHOT PEENING TO MAINTAIN HOLE DIA SPECIFIED.
    HOLE DIAMETERS TO BE CHAMFERED .030-.040X45° AFTER SHOT PEENING TO REMOVE MATERIAL BUILD UP. ALL SURFACE EDGES (EXCLUDING HOLE DIAMETERS) WITHIN THE AREA TO BE SHOT PEENED SHALL BE CHAMFERED .050-.070X45° PRIOR TO SHOT PEENING TO PREVENT MATERIAL BUILD UP.
12. 80/ FINISH APPLICABLE PRIOR TO SHOT PEENING AND AREAS HONED OR BURNISHED AFTER PEENING.
13. (-12 BELLCRANK ONLY) BREAK ALL SHARP EDGE TO .015"-.005 RADIUS OR CHAMFER.
14. PART NO. 107C2652-12 IS A CLASS B CRITICAL PART AND REQUIRES ALL TESTS AND RECORDS SPECIFIED THEREFOR IN BOEING PROCESS SPEC MS 14.00.
15. (-10 BELLCRANK ONLY) MARK SERIAL NUMBER WITH AN IDENTIFYING VENDOR LETTER PREFIX (AS ASSIGNED BY VERTOL MATERIAL) WITHIN AREA IN FIELD OF DRAWING IN .12-.15 HIGH LETTERS.
16. MATERIAL SUBSTITUTION & EQUIVALENTS PER D8-0127.
17. 107C2652-F13 FORGING IS SUITABLE SUBSTITUTE FOR 107C2652-F6.
18. -14 IS A MODIFICATION OF THE -7 OR -9 ASSEMBLY PER 107CK014.
19. INTERCHANGEABLE MIL-I-8500



MODEL	PART NO. CODE	NEXT ASSEMBLY
CH-46F	N5	A02C3000
107-II	N4	107CK002
107II-25	N4	107CK002
CH-46D	N3	A02C3000
107-II-25	N3	A02C3000
CH-46A	N3	A02C3000
107-II	N2	107C2080
107-II	N1	107C2700

Figure A4. Drawing 107C2652, Lateral Differential Bellcrank Assembly (Sheet 2 of 3)

VERTOL FINISH SPEC PS 362

REVISIONS

BY	ZONE	LET	DESCRIPTION	DATE
VS		A	CHANGED PER 2 C	
		B	CHANGED PER EO 6C	
		C	INCOR'D EO 7A ADDED PROPRIETARY NOTE	
VS		D	CHANGED PER EO 10C	
M L	C56	E	INC ADV EO 11A ADDED MIN WALL REQS.	
DWG		F	REVISED PER EO 12C	
R N	C14	G	INC ADV EO 13A ADDED ... R NO CALLOUT (2)14A ADDED ADDED NOTE 16.	10-17-66
L J M	C14	H	INC ADV EO 115A ADDED 17 (2)16A ADDED 18 NHA 107CK002 (3) UPDATED NHA BLK	5-28-67
R M N	C14	J	INC ADV EO 17A REV 61 SERIAL NO LOC	11-27-67
R L C	C4	K	INC ADV EO 118A REV 63 (2) 19A ADDED 19	7-19-68

DWG NO	ZONE	REV	TITLE		
107C2628	4C	E	SHAFT MIXING YOKE	N5 N6	-1E-2 -3E-4
107C2629	5C	D	BOLT-COLLECTIVE PITCH BELCRK UPPER CONTROLS	N5	-1
107C2651	18C	J	BELCRK ASSY LONG DIFF	N5	-12
107C2652	20C	L	BELCRK ASSY - LAT DIFF	N5	-11
107C2659	6C	C	NUT LONG CYCLIC "8" ACTUATOR	N2 N3	-1
107C2667	6C	D	LINK ASSY LATERAL UPPER CONTROLS	N5 N6	-1 -3

DIA FOR 107C1751-19

-7-031 BUSHING

DIA FOR NAS77-7-74

TO BE IN LINE

SPACER

DIA (TYP)

A BEARING

PLANE "Z"

			PART NO	DESCRIPTION	STOCK SIZE	MATL	MATL SPEC		FINISH			CODE NO FOR NEXT ASSY BLOCK	ZONE	NOTE	
			107C2652-14	BELLCRANK ASSY								N4		18	H

107C2652 REV L

			PART NO	DESCRIPTION	STOCK SIZE	MATL	MATL SPEC		FINISH		CODE NO FOR NEXT ASSY BLOCK	ZONE	NOTE	
–			107C2652-F13	FORGING (OPP)	NOTED	FORGING AL ALY 2014-T6	QQ-A-367 COMP 2014-T6	62	PS-362	63		C/10	61	
X			107C2652-11	BELLCRANK ASSY (AFT)					PS-362		N3 N5	A/18	19	
1			107C2652-12	BELLCRANK	MAKE FROM	-F13 FORGING			PS-362	PT		C/14	13, 14	
	1		107C2652-10	BELLCRANK	MAKE FROM	-F6 FORGING			PS-362	PT		C/14	15, 17	
	X		107C2652-9	BELLCRANK ASSY (AFT)					PS-362		N2, N3	A/14	19	
1			NAS75-7-025	BUSHING								A/18		
2	2	2	AN201KP12A	BEARING								C/5		
1			NAS77-7-55	BUSHING								A/18		
1	1	1	NAS77-7-74	BUSHING								C/16		
1			107C1751-25	BUSHING								A/18		
1	1	1	NAS75-7-031	BUSHING								C/5		
	1	1	NAS75-6-023	BUSHING								A/14		
1	1	1	NAS4300-12-69	SPACER								C/5		
	1	1	107C1751-45	BUSHING								A/14		
	1	1	107C1751-44	BUSHING								A/14		
1	1	1	107C1751-19	BUSHING								C/5		

107C2652 REV L

			PART NO	DESCRIPTION	STOCK SIZE	MATL	MATL SPEC		FINISH		CODE NO FOR NEXT ASSY BLOCK	ZONE	NOTE
			107C2652-F6	FORGING (OPP)	NOTED	FORGING MAG ALY ZK60A-T5	QQ-M-40A COMP ZK60A, TEMP T5	42		60		C/10	
			107C2652-F5	FORGING (SHN)	NOTED	FORGING MAG ALY ZK60A-T5	QQ-M-40A COMP ZK60A, TEMP T5	42		60		C/10	
		1	107C2652-8	BELLCRANK	MAKE FROM	-F6 FORGING			PS-362	(Z)		C/6	
			107C2652-3	BELLCRANK	MAKE FROM	-F5 FORGING			PS-362	(Z)		C/6	
		X	107C2652-7	BELLCRANK ASSY (AFT)					PS-362		N1, N2, N3	C/6	
			107C2652-1	BELLCRANK ASSY (FWD)					PS-362			C/6	
-11	-9	-7											

LIST OF MATERIAL

SECURITY CLASSIFICATION

CUSTOMER SIGNATURE ON RECORD

ONE-HALF SCALE COPY OF ORIGINAL DWG.

CODE IDENT 77272

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON NOTED

BELLCRANK ASSY LATERAL DIFFERENTIAL

Vertol

J 107C2652 L

SCALE FULL

107C1651

SHEET 1 OF 2

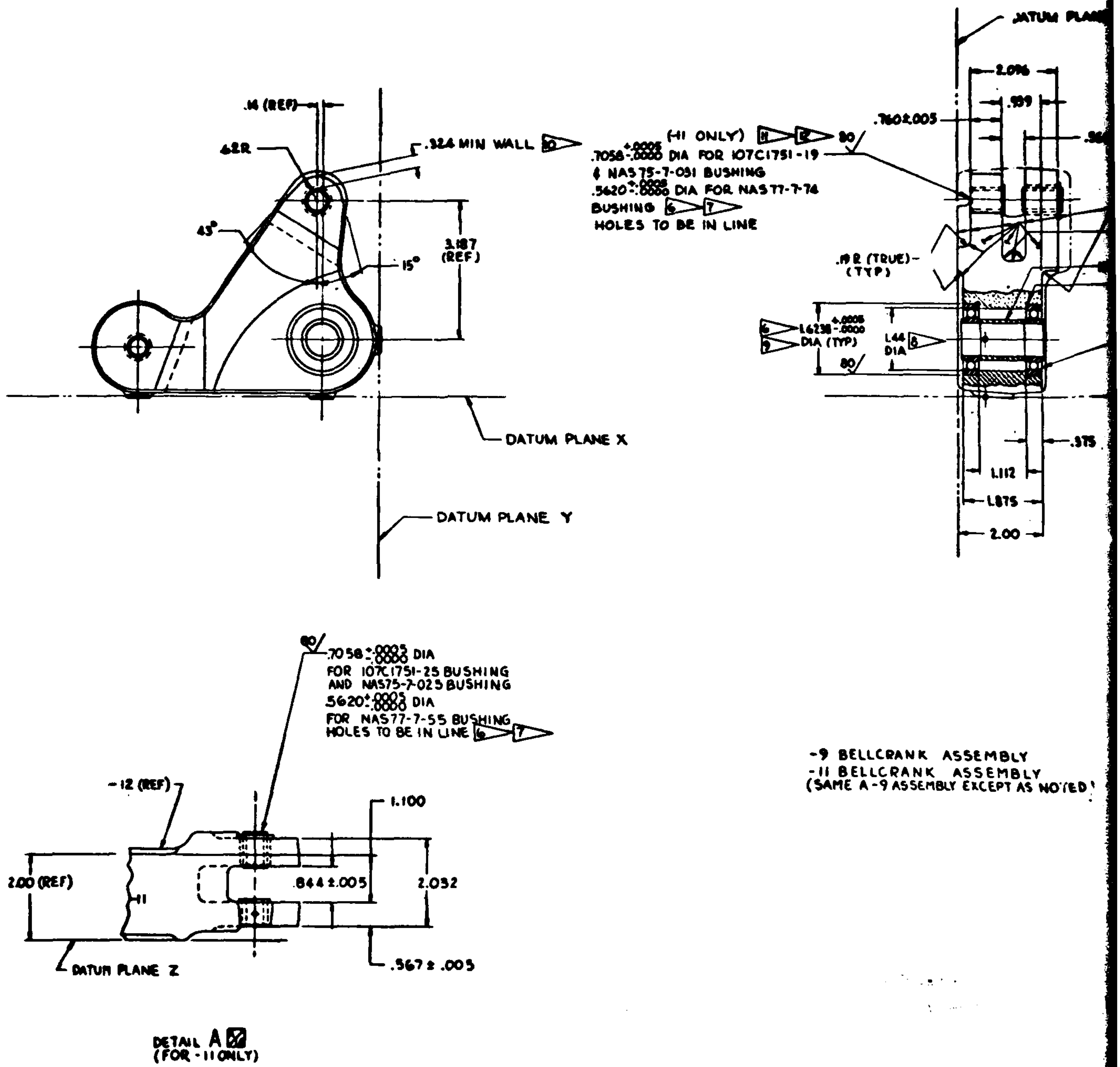
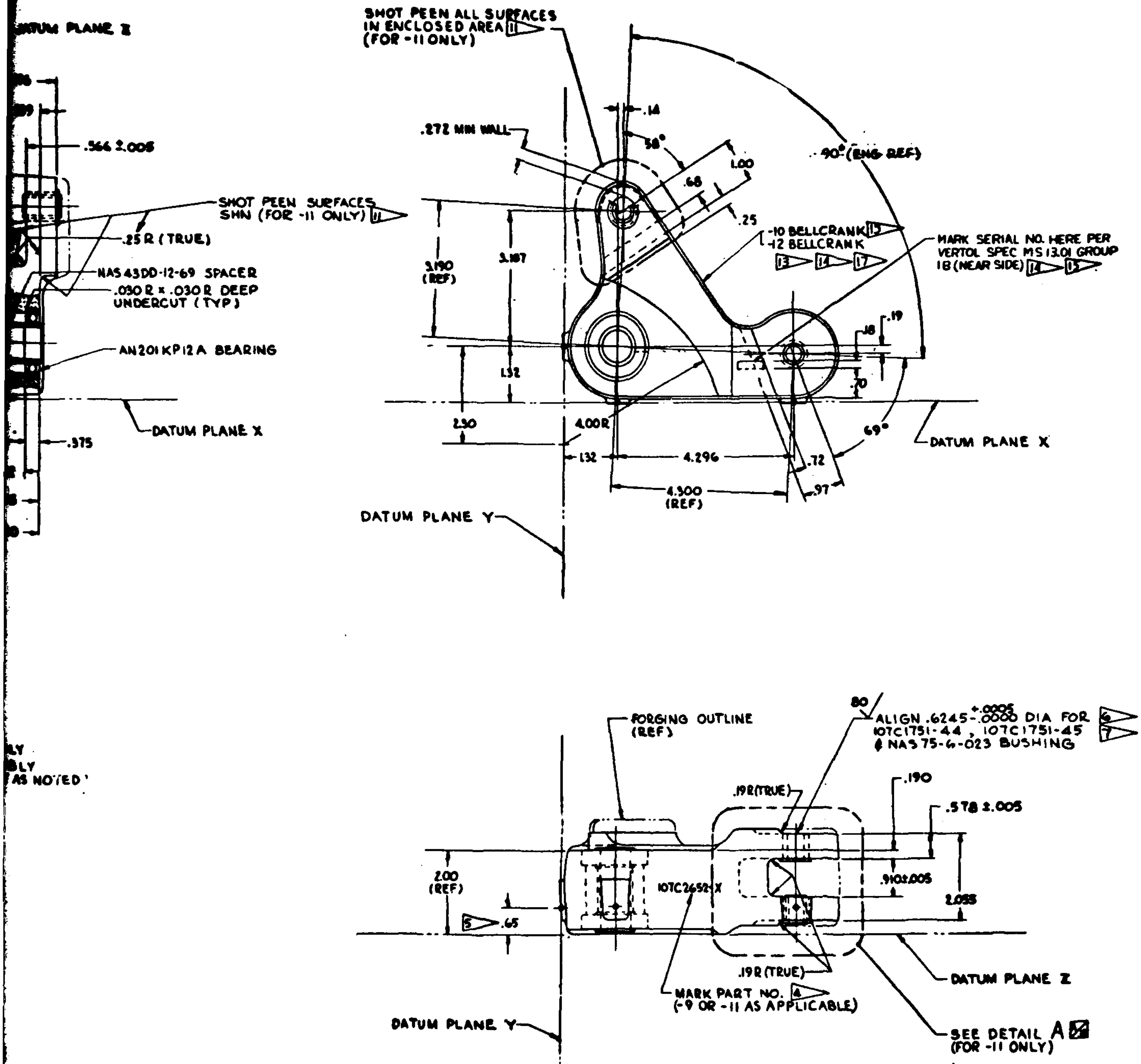


Figure A4. Drawing 107C2652, Lateral Differential Bellcrank Assembly (Sheet 3 of 3)



CODE IDENT NO 77272	SH
DWG. NO 107C2652	2

THIS DRAWING NOT COMPLETE WITHOUT APPLICABLE INFORMATION SHOWN ON SHEET 1.

BELLCRANK ASSY LATERAL DIFFERENTIAL

VERTOL

DWG NO J 107C2652

SCALE NOTED CODE IDENT NO 77272 SHEET 2 OF 2

DISTRIBUTION LIST

Director
Defense Research and Engineering Office
ATTN: DDRE (R&AT)
Washington, DC 20310

Director
Defense Advanced Research Projects Agency
ATTN: Dr. E. Van Reuth
1400 Wilson Boulevard
Arlington, VA 22209

Administrator
Defense Technical Information Center
ATTN: Accessions Division (DDC-TC) (12)
Cameron Station
Alexandria, VA 22314

Assistant Secretary of the Army (R&D)
ATTN: Deputy for Science and Technology
Washington, DC 20310

Deputy Chief of Staff for Research, Development and Acquisition
Department of the Army
ATTN: DAMA-ARZ-D
Washington, DC 20310

Commander
US Army Materiel Development and Readiness Command
ATTN: DRCMT, Mr. L. Croan (4)
5001 Eisenhower Avenue
Alexandria, VA 22333

Commander
US Army Armament Research and Development Command
ATTN: DRDAR SC, Col. A. J. Larkins
DRDAR-SCM-P, Dr. Waldman (7)
DRDAR-SCP
DRDAR-TSS (5)
Dover, NJ 07801

Commander
US Army Aviation Research and Development Command
ATTN: DRDAV-EXT, Mr. G. Gorline (10)
DRDAV-D
DRDAV-N
PO Box 209
St. Louis, MO 63166

Weapon System Concept TEAM/CSL
Attn: DRDAR-ACW
Aberdeen Proving Ground, MD 21010

Director
US Army Ballistic Research Laboratory
ARRADCOM
ATTN: DRDAR-TSB-S
Aberdeen Proving Ground, MD 21005

Technical Library
ATTN: DRDAR-CLJ-L
Aberdeen Proving Ground, MD 21010

Benet Weapons Laboratory
Technical Library
ATTN: DRDAR-LCB-TL
Watervliet, NY 12189

Commander
US Army Armament Materiel Readiness Command
ATTN: DRSAR-LEP-L
Rock Island, IL 61299

Director
US Army TRADOC Systems Analysis Activity
ATTN: ATAA-SL (Technical Library)
White Sands Missile Range, NM 88002

US Army Materiel Systems Analysis Activity
ATTN: DRXSY-MP
Aberdeen Proving Ground, MD 21005

Project Manager, Advanced Attack Helicopter
ATTN: DRCPM-AAH-TM
DRCPM-AAH-TP
PO Box 209
St. Louis, MO 63166

Project Manager
Advanced Scout Helicopter
ATTN: DRDAV-ASH
PO Box 209
St. Louis, MO 63166

Project Manager, Blackhawk
ATTN: DRCPM-BH-T
PO Box 209
St. Louis, MO 63166

Project Manager, CH-47
Modernization
ATTN: DRCPM-CH47M-T
PO Box 209
St. Louis, MO 63166

Project Manager, Aircraft
Survivability Equipment
ATTN: DRCPM-ASE-TM
PO Box 209
St. Louis, MO 63166

Project Manager, Navigation/
Control Systems
ATTN: DRCPM-NC-TM
Ft. Monmouth, NJ 07703

Project Manager, Tactical
Airborne Remotely Piloted
Vehicle/Drone Systems
ATTN: DRCPM-RPV
PO Box 209
St. Louis, MO 63166

Project Manager, Cobra
ATTN: DRCPM-CO-T
PO Box 209
St. Louis, MO 63166

Director
Applied Technology Laboratory
Research and Technology
Laboratories (AVRADCOM)
ATTN: DAVDL-ATL-ATS
Ft. Eustis, VA 23604

Director
Research and Technology
Laboratories (AVRADCOM)
Attn: DAVDL-AL-D
Moffett Field, CA 94035

Director, Langley Directorate
US Army Air Mobility R&D Lab
(AVRADCOM)
ATTN: DAVDL-LA
Mail Stop 266
Hampton, VA 23365

Director Lewis Directorate
US Army Air Mobility R&D Lab
ATTN: DAVDL-LE
21000 Brook Park Road
Cleveland, OH 44135

Commander
US Army Materials and Mechanics
Research Center
ATTN: DRXMR, Dr. E. Wright
Watertown, MA 02172

Commander
US Army Tank Automotive Research
and Development Command
ATTN: DRDTA-RKA, Mr. V. Pagano
DRSTA-RCM
Warren, MI 48090

Director
US Army Mobility Equipment Research
and Development Command
ATTN: DRDME-MMM, Mr. E. York
Fort Belvoir, VA 22060

Director
US Army Advanced Materials Concept
Agency
ATTN: Technical Information
Division
2471 Eisenhower Avenue
Alexandria, VA 22314

Director
US Army Industrial Base Engineering
Activity
ATTN: DRXIB-MT, Mr. G. Ney
Rock Island, IL 61299

Commander
US Army Research Standardization
Group (Europe)
ATTN: DRXSN-E-RM, Dr. R. Quattrone
PO Box 65
FPO, New York 04510

Commander
US Army Foreign Science and
  Technology Center
ATTN: Mr. W. F. Marley
220 Seventh Street, N.E.
Charlottesville, VA 22901

Commander
US Army Research Office
ATTN: Metallurgy & Materials
  Science Division,
  Dr. G. Mayer, Director
PO Box 12211
Research Triangle Park, NC 27709

Commander
US Army Missile Command
ATTN: DRSMI-ITE
Redstone Arsenal, AL 35809

Commander
US Army Electronics Command
ATTN: DRSEL-RD-P
Ft. Monmouth, NJ 07703

Commander
US Army Avionics Research and
  Development Activity
ATTN: DAVAA-O
Ft. Monmouth, NJ 07703

Commander
US Army Troop Support and
  Aviation Materiel Readiness
  Command
ATTN: DRSTS-PLC
  DRSTS-ME
  DRSTS-DIL
4300 Goodfellow Blvd
St. Louis, MO 63120

Commander
Naval Air Systems Command
Department of the Navy
ATTN: AIR 5203, Mr. R. Schmidt
Washington, DC 20361

Commander
US Naval Surface Weapons Center
ATTN: Dr. S. Fishman, R32
White Oak, MD 20910

Commander
US Naval Surface Weapons Center
ATTN: Mr. W. Mannschreck, Code G54
Dahlgren, VA 22448

Commander
Naval Air Development Center
  Johnsville
Aero Materials Department
ATTN: Mr. F. Williams
Warminister, PA 18974

Commander
Office of Naval Research
Dept of the Navy
ATTN: Code 423
Washington, D.C. 20025

Director
US Naval Research Laboratory
ATTN: Code 6300
Washington, D-C. 20390

Director
Air Force Materials Laboratory
ATTN: AFML/Technical Library
  AFML/LTM, Mr. B. Kosmal (4)
Wright Patterson Air Force Base
Dayton, OH 45433

Director
Air Force Armament Laboratory
ATTN: AFATL/DLOSL
Elgin AFB, FL 32542

Director Aeronautical System
  Division
ATTN: ASD/PMD (PESO), Mr. L. Clark
Wright Patterson Air Force Base
Dayton, OH 45433

Commander
Air Force Flight Dynamics Laboratory
ATTN: AFFDL/FB, Mr. L. Kelly
Wright Patterson Air Force Base
Dayton, OH 45433

Director
National Academy of Science
ATTN: Materials Advisory Board
2101 Constitution Avenue, N.W.
Washington, DC 20418

Metals and Ceramic Information
Center
Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201

Director
National Aeronautics and Space
Administration
ATTN: Code RRN
Federal Building No. 10
Washington, DC 20546

Director
National Aeronautics and Space
Administration
Geroge C. Marshall Space Flight
Center
ATTN: M-F & AR-M, Mr. W. Wilson
Huntsville, AL 35800

Director
National Bureau of Standards
ATTN: Technical Information
Division
Washington, DC 20025

Director
Atomic Energy Commission
ATTN: Document Library
Germantown, MD 21403

Director
Federal Aviation Administration
ATTN: Administrative Standard
Division
800 Independence Avenue, S.W.
Washington, DC 20590

AVCO-Lycoming Corp .
ATTN: Mr. V. Strautman, Manager
Process Technology Laboratory
550 South Main Street
Stratford, Conn 08497

Bell Helicopter Company
Division of Textron, Inc.
ATTN: Mr. P. Baumgartner, Chief,
Manufacturing Technology
PO Box 482
Ft. Worth, TX 76101

Boeing Aerospace Company
ATTN: D. B. Arnold
PO Box 3999, MS41-37
Seattle, WA 98124

Boeing Vertol Company
ATTN: Mr. R. Pinckney, Mfg Tech
Box 16858
Philadelphia, PA 19142

Detroit Diesel Allison Division
General Motors Corporation
ATTN: James E. Knott, General
Manager
PO Box 894
Indianapolis, Ind 46206

Fairchild Republic Company
ATTN: Mr. A. Shames
Farmingdale, L.I., NY 11735

FMC Corporation
ATTN: Mr. D. R. Fylling
1105 Coleman Avenue
Box 1201
San Jose, CA 95108

General Dyanmics Corp
Conair Aerospace Division
ATTN: W. Kao
Keraney Mesa Pland
San Diego, CA 92112

General Dynamics Corp
Fort Worth Division
ATTN: Dr. P. Mackmeier, MZ1860
PO Box 748
Ft. Worth, TX 76101

General Electric Company
ATTN: Mr. H. Franzen
10449 St. Charles Rock Road
St. Ann, MO 63074

Gould Inc., Gould Laboratories
ATTN: Mr. E. L. Thellman
540 E 105th Street
Cleveland, OH 44108

Grumman Aerospace Corp
ATTN: Dr. P. Adler
Bethpage, NY 11714

Grumman Aerospace Corporation
ATTN: Richard Cyphers, Manager
Manufacturing Technology, Plant 2
Bethpage, NY 11714

Hughes Helicopter
Division of Summa Corp
ATTN: Mr. R. E. Moore, Bldg 314 (2)
M/S T-419
Centinella Ave & Teale St
Culver City, CA 90230

ITT Research Institute
ATTN: Director of Research
10 West 35th Street
Chicago, IL 60616

Inco, Inc.
Inco, R&D Center
ATTN: Dr. R. D. Schelling
Sterling Forest
Suffren, NY 10901

Kaiser Aluminum & Chemical Co
The Center for Technology
ATTN: Mr. L. Barker
PO Box 877
Pleasanton, CA 94566

Kaman Aerospace Corp.
ATTN: Mr. A. S. Falcone
Chief, Materials Engineering
Bloomfield, CT 06002

Lockheed Georgia Company
D 72-26 Zone 329
ATTN: Dr. Walter Cremens
Marietta, GA 30060

Lockheed Missiles and Space Co.
ATTN: Mr. R. Lewis
M/S 52-31/204
3251 Hanover Street
Palo Alto, CA 94304

Lockheed Missiles & Space Co., Inc.
ATTN: H. Dorfman, Research
Specialist
Manufacturing Research
1111 Lockheed Way
Sunnyvale, CA 94088

Lockheed Missiles & Space Co., Inc.
ATTN: D. M. Schwartz
Dept 55-10, Bldg 572
PO Box 504
Sunnyvale, CA 94086

LVT Aerospace
Vought Aeronautics Division
ATTN: Chief, Mat'ls Processes
PO Box 5907
Dallas, TX 75222

Martin Merietta Aluminum
ATTN: Mr. D. Mellem
M/S 2601
19200 S. Western Avenue
Torrance, CA 90509

McDonnell Douglas Corp
Douglas Aircraft Co
3855 Lakewood Blvd
ATTN: Chief, Materials & Processes
Long Beach, CA 90846

Northrop
Mail Code 3872/62
ATTN: Dr. G. Chanani
3901 W. Broadway
Hawthorne, CA 90250

Rockwell International
North American Aircraft Division
ATTN: Chief Mat'ls & Processes
International Airport
Los Angeles, CA 90009

Rohr Industries, Inc.
ATTN: J. P. Ward
PO Box 878
Chula Vista, CA 92012

Sikorsky Aircraft Division
United Aircraft Corp.
ATTN: Mr. Melvin M. Schwartz,
Chief, Mfg. Technology
Stratford, CT 06497

United Technologies Corp.
Pratt & Whitney Aircrafts Div.
Manufacturing Research and
Development
ATTN: Mr. Ray Traynor
East Hartford, CT 06108

Vought Corp.
ATTN: Dr. D. H. Petersen
PO Box 6144
Dallas, Texas 75222

Wyman-Gordon Co.
ATTN: Mr. M. E. Rand
Worcester Street
North Grafton, MA 01536

Mr. J. C. Chang
R&D Engineering, M/S19T
Rohr Industries, Inc.
P.O. Box 878
Chula Vista, CA 92012

Prof. M. C. Flemings
Department of Metallurgy
Materials Science
Massachusetts Institute of
Technology
Cambridge, MA 02139

Dr. H. Hamilton
Rockwell International Science
Center
1049 Camino Des Rios
Thousand Oaks, CA 91360

Mr. H. Y. Hunsicker
Aluminum Co. of America
ALCOA Technical Center
ALCOA Center, PA 15069

Mr. M. V. Hyatt
Organization B-8833
Mail Stop 73-43
The Boeing Company
PO Box 3707
Seattle, WA 98124

Prof. C. Laird
Dept. of Metallurgy and Materials
Science
University of Pennsylvania
Philadelphia, PA 19174

Mr. H. Markus
550 S. Ocean Blvd
Apt 204-S
Boca Raton, Fl 33432

Mr. R. E. Newcomer
Dept. 247, Bldg 32
McDonnell Douglas Corporation
PO Box 516
St. Louis, MO 63166

Dr. E. J. Ripling
Materials Research Laboratory, Inc.
No. 1 Science Road
Glenwood, IL 60425

Mr. C. Spangler
Reynolds Metal Company
4th and Canal Streets
Richmond, VA 23261

Professor E. Starke
Fracture and Fatigue Research Lab
Georgia Institute of Technology
Atlanta, GA 30332

Mr. H. C. Turner
Branch Manager, Metallic Materials
Dept 372, Bldg 33
McDonnell Douglas Aircraft Corp
PO Box 516
St Louis, MO 63166

Mr. G. G. Wald
Dept 78-40, Bldg 63, Plant A-1
Lockheed Aircraft Company
PO Box 551
Burbank, CA 91503

Mr. Charles E. Doyle
Mail Zone 2830
General Dynamics
Fort Worth Division
PO Box 748
Fort Worth, Texas 76101

Mr. W. F. Bates
D/72-76
2329
Lockheed Georgia Co.
Marietta, GA 30063